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ELEMENTARY PRINCIPLES

OF

CARPENTRY.

BY

THOMAS TREDGOLD.

REVISED FROM THE ORIGINAL EDITION AND PARTLY RE-WRITTEN

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THIRD EDITION.

LONDON:

E. & F. N. SPON, 46, CHARING CROSS.

NEW YORK, 446, BROOME STREET.

1880.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

PREFACE.

A CONSIDERABLE time having elapsed since this work had been revised by the Author, a new Edition that would embrace recent improvements and examples was much required. Since Tredgold's death in 1829 our stock of knowledge regarding the strength of materials has been largely increased, owing to the labours of Hodgkinson, Kirkaldy, and others. The rapid development of the railway system throughout the world has contributed greatly to the introduction of new methods and to the multiplication of examples in the art of construction. More perfect and scientific appliances in the erection of large works have been substituted for the primitive methods used in the last generation. These have all tended more or less to tax the ability and knowledge of the carpenter. The opening up and development of the resources of new countries have introduced varieties of timber, many of them possessing useful properties, not the least of which is that of resisting the attack of sea-worms and insects—a cause of destruction that has hitherto been a source of much anxiety to the Profession.

In order to adapt this work as far as possible to the requirements of the modern carpenter, it has been necessary to re-write the articles on Pillars, Bridges, and Timber; to add new sections on Coffer-dams, Scaffolds, &c.; and to

revise the remainder of the work throughout. And for the more complete illustration of these subjects several new Plates and Woodcuts have been added.

The Editor trusts that this Edition will merit the confidence of the Profession as a book of reference, and afford at the same time valuable assistance to the student.

LONDON, *20th April*, 1871.

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ELEMENTARY PRINCIPLES

OF

CARPENTRY.

INTRODUCTION.

ART. 1. Carpentry is the art of shaping and combining pieces of timber to support weight or to resist pressure, and is governed by the science of mechanics.

The mechanical principles of carpentry, as given in the following work, are divided into two branches, *viz.* the EQUALITY AND DISTRIBUTION OF FORCES, which show how stresses are transmitted through a system of framing; and the STRENGTH OF MATERIALS, by which a knowledge of the resistance of the parts is obtained.

2. In another division of this work are shown a few of the Forms into which timber has been wrought, and the purposes to which it has been applied, in the art of carpentry, such as Floors, Roofs, Scaffolds, Centres, Coffer-dams, Bridges, &c., and the application to such structures of Rules and Formulæ derived from the principles of mechanics.

It is good workmanship, for which some knowledge of geometry is required, and the application of the principles of mechanics, that constitute carpentry an art; for unless timbers are well proportioned, well placed, and well fitted, the stability

of the structure will be uncertain, and a useless expenditure may have been incurred.

Want of mechanical knowledge in the early days of bridge-building caused many failures in the construction of centres for the support of the arches; and in the infancy of railway engineering it led to wooden bridges, particularly those of the lattice type, being brought into disrepute, owing to imperfections in the design; and similar imperfections in the works of some of our great public departments have been, within a very recent period, noticed by the public press.

3. The education of the carpenter would not be complete without a knowledge of the materials on which his skill is to be exercised. Therefore it becomes essential towards the completeness of the present work to treat of the characteristics and varieties of timber, the localities where it can be obtained, and the uses to which it may be applied. Also, as the carpenter has no immunity in the preservation of his materials, it is necessary that he should have some knowledge of the conditions which lead to their decay, and the means by which their durability may be increased. Indeed, a complete inquiry into this subject would presuppose an acquaintance with branches of natural history and chemistry, for the study of which few carpenters have the leisure or even the facility.

SECTION I.

OF THE EQUALITY AND DISTRIBUTION OF FORCES, OR TRANSMISSION OF PRESSURE THROUGH BEAMS.

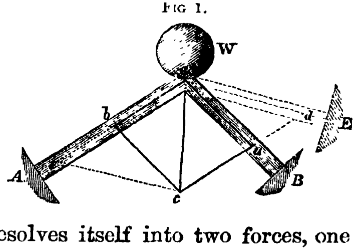
4. It is through a knowledge of the composition and resolution of forces alone that the carpenter can expect to arrive at excellence in the art of designing frames of timber, as without this knowledge it would be impossible for him to understand clearly what is to be aimed at in such designs: or even to know whether a design of his own would answer its intended purpose or not.

The first step towards obtaining this knowledge, is to acquire just notions of the action of forces.

5. A heavy body exerts in a vertical direction a force equal to its own weight; and it would always descend in a vertical line, if not moved out of that direction by some other force.

6. But when a heavy body W (Fig. 1) is sustained by two beams A C and B C, its effects on these beams depend on their position; the farther the ends A and B are set apart, the greater will be the sum of the strains on the beams; and the contrary. Here it is obvious the weight resolves itself into two forces, one in the direction of each beam, or we may consider that the abutments A and B exert reactionary forces through the beams in the opposite direction, which are sufficient to support the weight. These are evidently equal to the forces

FIG. 1.



caused by the weight, for action and reaction are equal and opposite.

We may now proceed to explain what is meant by the composition and resolution of forces.

OF THE COMPOSITION AND RESOLUTION OF FORCES.

7. The *resolution of forces* consists in finding two or more forces which shall have the same effect as a single force. For the weight W (Fig. 1) might be sustained by a vertical force in the direction *c* C equal to it; or this vertical force, it is obvious, may be resolved into two forces in the directions of the beams capable of producing the same effect as the vertical force C *c*.

8. The *composition of forces* consists in finding one force that shall produce the same effect as two or more forces acting in different directions. This is nothing more than the reverse of the resolution of forces, and may be accomplished in a similar manner.

9. If a vertical line C *c* (Fig. 1) be drawn through the centre of the weight, and *a c* be drawn parallel to the beam A C; also *b c* parallel to B C; then the relations between the weight and the pressures will be found by the following proportions:

As the line C *c*,
Is to the line C *b*;
So is the weight W,
To the pressure in the direction of the beam A C.

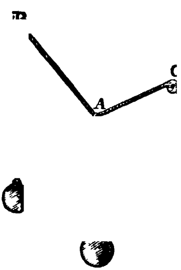
Also, As the line C c,
Is to the line C a;
So is the weight W,
To the pressure in the direction of the beam C B.

To those who are acquainted with the principles of mecha-

nics the truth of the principle from which these proportions are derived requires no illustration; but such as have not had the advantage of that branch of learning may, by having recourse to the following simple experiment, not only satisfy themselves of its truth, but also render themselves more familiar with the nature of forces.*

10. Let a thread or fine line be passed over the pulleys B and C (Fig. 2), and let a known weight be attached to each end of the line, as at *b* and *c*; also let another thread be knotted to the first one at any point A, and attach a known weight to the end W. Then if the sum of the weights *b* and *c* be greater than the single weight W, there is a certain position in which the assemblage will be at rest; and if it be deranged by pulling at any of the weights it will return of itself to the same position when left at liberty.

FIG. 2.



Therefore, in that position, and in that position only, the weights will balance one another, or be in equilibrio. Now, if the positions of the threads, when the weights balance one another, were drawn upon paper; and, from a scale of equal parts, A F were made equal to the number of pounds in the weight W, and the line B A were continued to E, and the line F E drawn parallel to A C, then F E measured by the same scale of equal parts would show the number of pounds in the weight at *c; also the measure of the line A E would be equal to the number of pounds in the weight b.*

* The reader who wishes to have more scientific information on the subject will find it ably handled in Gregory's 'Mechanics,' vol. i., chap. 2; he may also consult Rankine's 'Applied Mechanics,' Fenwick's 'Mechanics of Construction,' or Byrne's 'Elements of Practical Mechanics.'

If the three weights be equal, then the three lines A F, F E, and A E will be equal, and the angles formed by the threads round the knot will be equal.

11. And universally whenever the directions of three forces are in the same plane, and meet in a point, and are in equilibrio, those forces will be represented in magnitude by the three sides of a triangle drawn parallel to the directions of the forces.

12. Consequently, if a body be kept at rest by three forces, and any two of them be represented in magnitude and direction by two sides of a triangle, the third side taken in order will represent the magnitude and direction of the other force.

13. Also because the sides of triangles are as the sines of the opposite angles, it follows that when three forces keep a body in equilibrio, each force is proportional to the sine of the angle made by the direction of the other two. Thus, if the weight W (Fig. 2) be as the sine of the angle A E F, the weight *b* will be as the sine of the angle A F E, &c.

It may, however, be observed, that the designs of framing are always drawn on paper to a scale; hence the proportions of the forces may be obtained immediately from the figure without the trouble of calculation, and the values so obtained will be accurate enough for any practical purpose. This method then will be adopted in the following pages whenever it is found most convenient.

14. Again, considering the combination of forces in Fig. 1; let the vertical line C *c* be drawn, and by a scale of equal parts make C *c* equal to the number of pounds, hundred-weights, or tons contained in the weight W. Then draw *c b* parallel to B C, and *c a* parallel to A C; and C *b*, measured from the same scale, will show the number of pounds, hundredweights, or tons by which the beam C A is strained; and, in like manner, C *a* will be the measure of the strain on

the beam C B, in pounds, hundredweights, or tons. The pressure is not altered by making the beams longer or shorter, so long as their positions remain the same; but the power of a beam to resist pressure is much lessened by increasing its length. The effect of this power will be considered in another part of the work (see Section II.). Only it may here be remarked, that when one beam is much longer than another in a system of framing, the position of the line of direction of the weight will vary a little from its intended position; because a beam of ten feet will compress twice as much as one that is only five feet long, and this will cause a corresponding change in the directions of the forces. Also if a beam that has to sustain a pressure in the direction of its length be joined in several places, it will yield more than one that has no joints except those at its ends; and the yielding will be nearly in proportion to the number of joints, supposing them all to be equally well made; for it is impossible to make a joint that will not yield in some degree.

Changes of form in an assemblage, or system of framing, almost always increase the effect of the weight, and often produce cross-strains that are attended with the worst consequences when such changes are not foreseen, and provided for accordingly.

Effect of Position.

15. If the position of the beam C B (Fig. 1) were changed to that shown by the dotted lines C E, the strain would be greatly increased on both beams. By drawing lines parallel to the beams in this position, expressing the weight by the line C *c* as before, the pressure on the beam in the position C E will be measured by the line C *d* instead of C *a*; while the strain on the beam C A will be nearly doubled, being represented by the line C *e*.

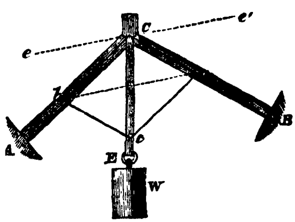
Hence it appears that enormous strains may be produced

by a comparatively small weight, merely by altering the position of the supports. The reader will do well to consider these changes with attention, and to draw figures in different positions, estimating the pressures according to each position, which will render his mind familiar with the subject, and enable him in practice to form accurate notions of the various strains without the labour of calculation.

To Measure the Strains in a Framed Truss.

16. If, instead of placing the weight on the point where the beams meet, the beams were framed into a piece of timber, C E (Fig. 3), and the weight W suspended at E, the pressures would still be transmitted in the same manner, and would be found by the same means; C c representing the weight, C b the pressure in the direction of the beam C A, and C a the pressure in the direction of the beam C B.

Fig. 3.



In this case C E performs the office of the king post in a roof.

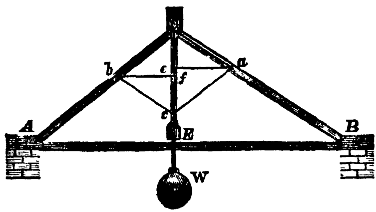
17. Hitherto the ends of the beams, marked A and B in Figs. 1 and 3, have been considered to be retained in their place by immovable supports; but they obviously have a tendency to spread; therefore they might be connected by a rope, a rod of iron, or another beam, which would answer a purpose nearly similar to the tie-beam of a roof. It is not quite the same, because a tie-beam has in general to support a ceiling, for which purpose a rope or rod of iron would not be sufficient.

Let Fig. 4 represent an assemblage of this kind, where A B is the tie to prevent the lower ends of the beams A C and

C B from spreading. This form is similar to
roof with a king post.

The strain on the tie A B may be found by drawing $b f$ parallel to the tie A B; then, if C b represent the pounds or tons with which A C is pressed (found by Art. 14); $b f$, measured from the same scale, will be equal to the strain in

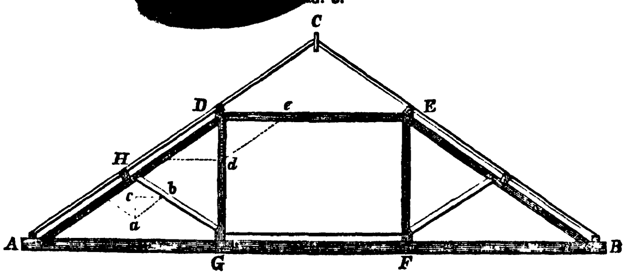
FIG. 4.



th[illegible] length of the beam or tie A B in pounds [illegible]nd opposite strain at B is measured

[illegible] is a roof with queen posts, the [illegible]C and C B and tie-beam A B,

[illegible]. 5.



arising from the weight of the roof, may be found in the same way as in a king-post truss. The strain on the strut H G may be found by drawing a vertical line H a to re-

present the vertical weight supported at H, and lines drawn from *a* parallel to the rafter and strut will represent the pressures in these directions respectively.

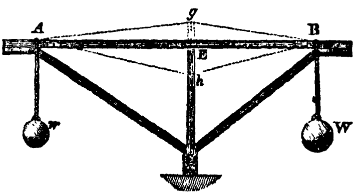
The horizontal line *c b* will represent the thrust on the straining sill G F, and the portion of the vertical line H *a* between H and *c* will represent the vertical pressure on the foot of the queen post D G or E F.

In a similar manner the stress on the straining-beam D E may be found, the vertical distance D *d* being set off equal to the portion of the weight of the roof supported at D *plus* the downward pull on the queen post D G, which is equal to the vertical pressure caused by the strut H G, and a portion of the load supported by the tie-beam, usually the floor of a garret, between G and F, and the ceiling of the rooms underneath.

Of Framed Levers.

18. Let Fig. 4 be inverted, and supported at C, as represented in Fig. 6, and a weight hung at each end, so as to balance one another; then the proportion of the strains would remain precisely the same; and it shows how a powerful lever may be framed, and also makes us acquainted with the nature of the strains produced in a solid beam when it performs the office of a lever. The tie A B is in a state of tension, the beams A C and B C are compressed; in a solid beam the same thing takes place, the side next the support is always compressed, and the opposite side is always in a state of tension.

Fig. 6.



It may be observed that when the frame is inverted, as in Fig. 6, and the tie A B is perfectly straight, there is no strain

C A; these lines being each measured by the scale will give the values of the strains in pounds.

If the position of the beams in Fig. 7 were changed to that shown in Fig. 8, the beam B C would still act as a strut, that is, the weight would have a tendency to compress it: this is evident, because, notwithstanding its inclined position, its place could not be supplied by a rope, which would be the case if it were only stretched.

FIG. 8.

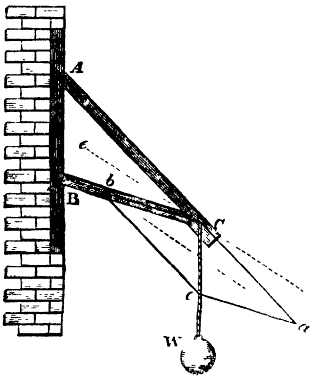
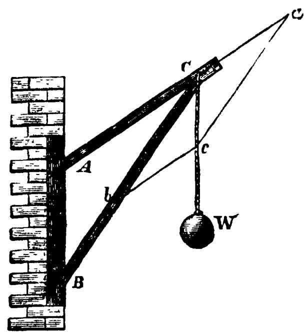


FIG. 9.

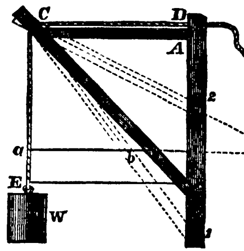


Also, in Fig. 9, A C is in a state of tension, and its place might be supplied by a rope, though it appears from its position to act as a strut. In either of these cases the strains may be estimated as in Fig. 7. As the line representing the weight is the same in each, by comparing the figures it will be seen how much the pressures are increased by altering the position of the beams.

20. The last three figures are each similar to the jib of a crane, but the strain upon the jib of a crane is very different. This difference we will endeavour to explain, and in so doing will point out some principles that ought to be attended to in the construction of jibs.

Let D C E represent the rope by which the weight is raised (Fig. 10) passing over a pulley at C; it is clear that the strain in the direction C D is equal to the strain in the direction C E; but in each of the cases represented in Figs. 7, 8, and 9, the strain was in the direction C E only.

FIG. 10.



Now if we make C E equal to C D, and draw B E parallel to D C, cutting the line D B in B; then joining B C, we have the direction of a beam that would sustain the forces in the directions D C and E C; and the beam placed in the direction B C would sustain the whole effect of the strains with the least force possible, only requiring a piece A C to steady it.

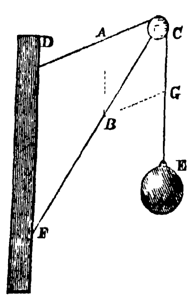
But when the beam B C is placed at any other position than that found by constructing a parallelogram on the directions of the ropes, the effect of the straining forces will be increased, and will vary according to the position of the sustaining beams. For example, let the beam B C be removed to the position shown by the dotted lines B^1 C. Then both A C and B^1 C will be in a state of compression. Let the vertical C *a* represent the weight W, then C *b* will represent the force in the direction of the beam in the position C B^1; and *b c* that compressing the beam A C, from which the equivalents of these forces in pounds or other weights may be ascertained.

Again, suppose the beam B C to be removed to the position shown by the dotted lines B^2 C, instead of B^1 C, then it would be compressed, and the strain nearly doubled, while the beam A C would be in a state of tension under a considerable strain. This is the most defective form for a crane

jib; yet it is that which is most commonly used. When C a[*] represents the weight W, C e represents the pressure on the beam B^2 C; and $c\,e$ the tension on the beam A C; and being compared with the same line to represent the weight, in each case we see how devoid of principle are the usual methods of construction and how obvious the means of improvement.

21. The beam B C in the jib of a crane is called the *spur*, and the position, so that it shall be the best adapted for the purpose, appears to be a little below the diagonal of a *parallelogram, constructed on the directions of the ropes. This diagonal may be found as follows:*—Let D F be the shaft (Fig. 11) and D C, C E, the directions of the ropes for raising the weights. Make C A equal to C G, and draw B G parallel to A C, and A B parallel to C G; then join C B and it is the diagonal required. Then, to place the foot of the spur a little lower than the point F, where the diagonal cuts the line of the shaft, causes both the spur and head-piece to be compressed, and produces the strongest arrangement, and one that will move more steadily than any other.

FIG. 11.



It is scarcely necessary to state that in all these cases the beams have been supposed to be capable of motion at the joints or points of connection; as the firmness that can be given at the joints is so very small in heavy framing that its effect, in all cases where calculation is necessary, may be left out of the question. The methods of connecting or joining framing will be considered in a separate section.

To distinguish Ties from Struts.

22. It is necessary, in estimating the strength of framing, that we should be able to distinguish the struts from the ties; that is, to ascertain what beams are compressed, and what are stretched. By attending to the following considerations, this may be easily determined. From the point on which the straining force is exerted, draw a line in the direction it would move in, if the framing were taken away. When this line falls within the angle formed by the pieces strained, then both pieces are compressed. But when it falls within the angle formed by producing the directions of the sustaining pieces, then both the pieces are in a state of tension.

The following method is a more general one, and includes the case just stated.

23. Let a parallelogram be constructed, on the direction of the straining force as a diagonal, the sides of the parallelogram being parallel to the sustaining forces; then, let the other diagonal of the parallelogram be drawn; and parallel to it, draw a line through the point where the directions of the forces meet. Consider towards which side of this line the straining force would move if left at liberty; and all supports on that side will be in a state of compression, and all those on the other side will be in a state of tension.

The same thing would be true of a plane passing through the point where three or more forces meet, which are not in the same plane; but such cases are of rare occurrence; therefore, if we show how the method applies to the examples in Figs. 3, 7, and 8, the reader will be able to apply it to all cases where the sustaining forces are in the same plane.

In Fig. 3, 7, 8, and 9, Cc is the direction of the straining

force, on which as a diagonal the parallelogram $C\,b\,c\,a$ is drawn, the sides of it being parallel to the resisting or sustaining beams: join $b\,a$, and draw the dotted line $e\,e'$ parallel to $b\,a$ in each figure; then, in Fig. 3, the straining force would move towards E, if left at liberty; therefore both tne beams are compressed, being on that side of the line $e\,e'$.

In Figs. 7, 8, and 9, only the lower sustaining beams are compressed, the upper ones being extended; and if the line $e\,e'$ were drawn to Fig. 2, it would show that both the supports are in a state of tension.

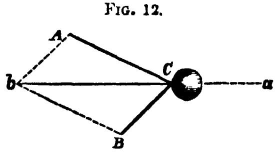
To find the Resultant of a System of Forces.

24. As the strain upon a piece of framing is often produced by two or more forces, acting in different directions, of which the crane is an instance, the means of finding a force and its direction that would be equal in effect to two or more forces may be next considered a little more attentively. In all cases where the strain is produced by the action of several forces meeting in one point, these forces must be reduced to a single force, capable of producing the same effect; otherwise it will not be possible to determine the strain upon the supports.

25. A force capable of producing the same effect as two or more forces, is called the *resultant* of those forces.

Let A C represent the magnitude and direction of a force, acting on the body C (Fig. 12), and B C the magnitude and direction of another force also acting on the body C. Then to find the resultant, draw b B parallel to A C; and A b parallel to B C; join b C, which represents the resultant required. The lines connecting the points A, C, B, b, form a parallelogram, of which b C is the diagonal; and

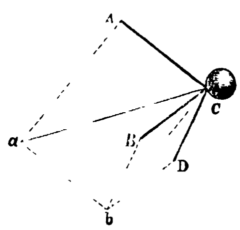
Fig. 12.



whenever two sides of a parallelogram are parallel to the directions, and proportional to two forces, the diagonal will represent the direction and amount of a single force that would produce the same effect. A parallelogram constructed in this manner is called a *parallelogram of forces.*

Also, if the force b C were to act in the opposite direction, that is, from a towards C, it would retain the two forces A C and B C in equilibrio; but two forces only can never be in equilibrium unless their directions be exactly opposite, and the forces equal; and the direction they would move in when not exactly opposite, is shown by producing the diagonal of the parallelogram drawn on their directions. Thus C a (Fig. 12) is the diagonal produced, and consequently the direction in which the forces A C and B C would cause the body C to move.

26. If it were required to find the resultant of three forces pressing on the point C, of which the magnitudes and directions were represented by the lines A C, B C, and D C (Fig. 13). In the first place complete the parallelogram B C D b, as in the preceding example; from which we find b C to be the resultant of the two forces B C and D C. Then consider b C and A C as two forces, and complete the parallelogram A a b C, and a C is the resultant required; that is, a force, the magnitude and direction of which is represented by a C, would produce the same effect in moving the point C as the three forces A C, B C, and D C. Also, a force equal to a C, and opposite, would keep these three forces in equilibrio.



By pursuing the same method of reduction, the resultant of any number of forces tending to one point may be found; but the same thing may be effected more simply as follows:—

27. Let A C, B C, and D C (Fig. 14) be the three forces;* beginning at any force, as at B, make B *a* parallel and equal to the next force D C; and then make *a d* parallel, and equal to the other force A C; join *d* C, and it is the resultant of the three forces.

The figure B *a d* C is called the *polygon of forces*, and the number of its sides will always be one more than the number of the forces.

Fig. 14.

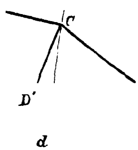
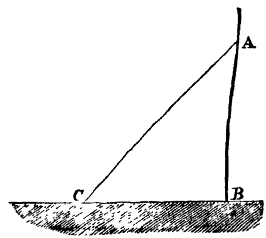


Fig. 15.

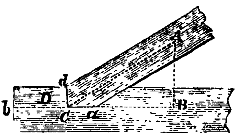


28. When any strain is produced by a single force it is sometimes useful to know its effect in a particular direction, in order to apply an equivalent support in that direction. Thus, when a force acts obliquely against the plain surface of an immovable obstacle, the force will have a tendency to slide along the plane; because two forces cannot sustain each other unless they be equal and opposite. Let a force A C (Fig. 15) act upon the even surface of a plane C B; it is evident that only part of this force will be exerted in a direction perpendicular to the plane, and this part will be represented by the line A B, drawn perpendicular to the plane; and then, C B will represent the force that would prevent its sliding along the plane.

* Where forces are represented in magnitude and direction by lines, the lines only are used for the sake of clearness and conciseness to express the forces.

When two pieces of timber are joined obliquely, the pressure on the different parts of the joint may be ascertained by this method; for example, let D B (Fig. 16) represent the end of a tie-beam, and A C the principal rafter; the force in the direction of the rafter being represented by A C. Then A B being perpendicular to the part C *a* of the joint, will represent the pressure upon it, and the pressure on the part C *d* will be represented by C B; consequently C B will be the measure of the force tending to splinter off the part D. *(See Sect. on 'Joints.')*

FIG. 16.



We cannot often oppose a force by one directly opposite, but we can generally find two forces that will answer the purpose; and by describing a triangle on their directions, and that of the force to be supported, their proportions can always be ascertained. This principle is most important in the theory of carpentry.

29. In general the designs for framing may be so contrived, that the load rests upon two or more points; for example, the weight of a roof acts on the truss which supports it, only at the points where the purlins bear upon the truss; and when these points are supported by struts, the forces may be considered, without material error, to be in the direction of the principal rafters. But when the load is uniformly distributed over the rafter, and it is supported at the ends only, the strain upon the tie-beam is no longer in the direction of the rafter: and as there are some important strains produced by the action of uniform loads, the nature of these strains will form the next object of inquiry.

In order to render the inquiry more clear and simple, let the load be supposed to arise from the weight of the beams themselves.

Of the Centre of Gravity.

30. In a beam there is a single point, by which it may be supported, and if so supported, it may be placed in any position, and remain at rest. Whereas, were it supported by any other point, it would rest only in certain positions.

This point is called the *centre of gravity* of the beam.

A beam A B, suspended by a pin at C (Fig. 17) passing exactly through the centre of gravity, will rest in the position A B; or in that shown by the dotted lines *a b*, or any other. And the same will be the case let the body be ever so irregular, provided the support passes exactly through the centre of gravity.

The centre of gravity of an uniform cylinder or prism, is at the middle of its axis.

In a triangle the centre of gravity is in a line drawn from the vertex to the middle of the base, and at the distance of one-third of that line from the base.

In cones or pyramids the centre of gravity is one-fourth of the height from the base.

Fig. 17.

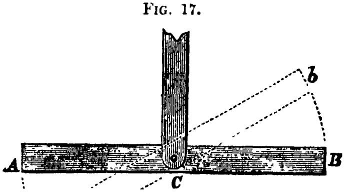
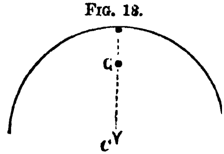


Fig. 18.

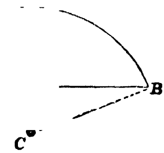


The centre of gravity of a circular arc (Fig. 18), is in a line drawn from its centre to the vertex, and at the distance from the centre equal to the chord multiplied by the radius of the circle, and divided by the length of the arc.

When the arc is a semicircle the distance from the centre equals the radius multiplied by ·63662.

In a circular segment (Fig. 19) it is in a line drawn from the vertex to the centre of the circle of which the segment forms a part, and at a distance from that centre equal to the cube of the chord A B divided by twelve times the area of the segment.

FIG. 19.



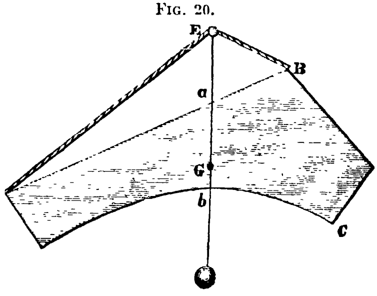
When the segment becomes a semicircle, the distance equals the radius multiplied by ·42441.

The place of the centre of gravity in various planes, lines, and solids, has been determined by mechanical writers; and as the subject is considered in most works on mechanics,* it is not necessary to enlarge upon it here; because when the rules become complicated it is easier to ascertain it by mechanical means, and in irregular figures such contrivances must be resorted to.

The most useful mechanical methods of finding the centre of gravity are the following:—

31. To find the centre of gravity of a body with plain sides, suspend it by the cord A E B (Fig. 20) fixed to the body at A and B, and passing over a pin E. When the body is at rest by means of a line and plummet, draw a plumb or vertical line upon it, as at *a b*. Then, slide

FIG. 20.

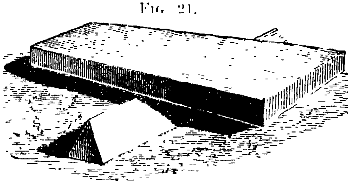


* See Gregory's 'Mechanics,' vol. i., chap. iii.; or Marat's 'Mechanics,' Book i., sect. iii.

the cord upon the pin E, so as to change the position of the body as much as possible; and when it is at rest again, draw another vertical line upon it, and where this vertical line crosses the former one will be the centre of gravity of the body.

32. Another method. Balance the body upon the edge of a triangular prism (see Fig. 21), and mark a line upon it close by the edge of the prism; then change the position of the body upon the prism, balance it again, and a line drawn by the edge of the prism will cross the former one, and the point of intersection will indicate the place of the centre of gravity which is within the body.

Fig. 21.



The intersecting lines should cross each other nearly at right angles if possible, as the nearer they cross at right angles the more accurately the point will be found.

The same thing may be done by laying the body upon a bench, and moving it so as to balance over the edge, or till it be just on the point of falling off. Then mark a line along by the edge of the bench, and do the same in another position, which will in like manner determine the centre of gravity.

33. It is a principle in mechanics, that when a body is supported and at rest, the directions of the supporting forces must either meet at the centre of gravity, or in a vertical line passing through it, unless the forces be parallel to one another.*

34. And when a body is supported by one or more planes, and the body is at rest, the pressure on the planes is in

* Gregory's 'Mechanics,' vol. i., art. 106.

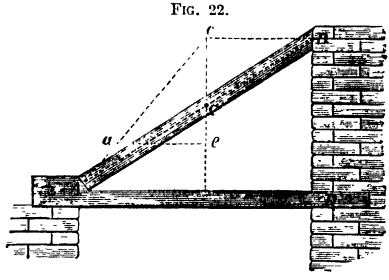
a direction perpendicular to their surfaces; when the pressure upon the plane is in an oblique direction, the body will not remain at rest, unless it be in consequence of the friction of the surfaces, a subject which is neglected in the present inquiry.

By the help of these principles it will be easy to determine the direction of the pressures produced by a heavy beam or other body in some of the most useful cases.

OF THE PRESSURE OF INCLINED BEAMS.

35. Let A B (Fig. 22) be a beam resting against the vertical wall B D, and C its centre of gravity; the lower end resting on an abutment cut in the beam A D. Through the centre of gravity C, draw the vertical line *c e*; and draw *c* B perpendicular to B D, meeting *c e* in *c*. Join A *c*, which will be the direction of the pressure against the abutment at A; and that the beam may have no tendency whatever to slide, the abutment should be perpendicular to A *c*.

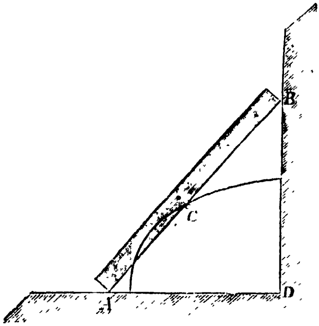
FIG. 22.



Also, if *c e*, taken from a scale of equal parts, represent the weight, and *a e* be drawn parallel to *c* B, then *a e* will represent the pressure against the wall at B, and *c a* the pressure against the abutment at A. The horizontal thrust at the abutment A, is also measured by the line *a e*; as it is always equal to the horizontal pressure against the wall at B. The pressures of shed or lean-to roofing are shown by this example.

36. Let A D (Fig. 23) be a smooth horizontal plane, and B D a smooth vertical plane; the force which the end A, of *the beam A B, would exert in a horizontal direction in any position of the beam,* may be found by the equation $\frac{W \times m \cos. a}{h}$ = the horizontal thrust. Where W is the weight of the beam, *m* the distance of the centre of gravity A C from the lower end; *a* the angle which the beam forms with the horizon; and *h* the height B D of the upper end of the beam.

FIG. 23.



It is evident from this equation, that when the weight is the same, the length of the beam does not alter the horizontal thrust, while the angle of inclination and distance of the centre of gravity are not varied; and that the horizontal thrust increases in proportion to the distance of the centre of gravity from the lower end, and that it also increases as the angle of inclination decreases.

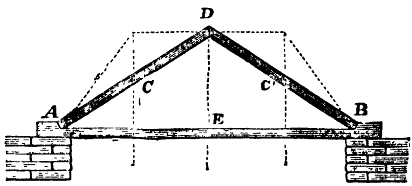
37. It has been already stated, that the abutment should be perpendicular to the direction of the pressure (Art. 35); and it may be shown that the tangent of that angle which the abutment for the lower end should form with the horizontal plane is equal to $\frac{m \times \cos. a}{h}$; which becomes $\frac{\text{A D}}{2\,h}$ when the centre of gravity is at the middle of the length of the beam. Hence the angle may be easily calculated.

38. When the beam moves between the planes, so that the lower end slides along the plane A D (Fig. 23) and the upper end down the plane B D, the point C opposite the centre of

gravity will describe a portion of an ellipse of which B C will be the semi-transverse, and A C the semi-conjugate axis. And when the centre of gravity is in the middle of the length of the beam, it will describe a circle; of which the radius is equal to half the length of the beam. This curious property may in many cases be applied to describe an ellipse on a large scale with advantage, as it is simple and easy to put in practice almost in any situation. The line in Fig. 23 shows the part of an ellipse so described.

39. When two similar and equal beams A D and D B are placed in the position represented in Fig. 24; C C′ being their centres of gravity; then their pressures against each other, at the point where they meet, will be equal and opposite; and their horizontal thrusts will also be equal. and may be found by Arts. 35 and 36; as each beam is obviously in the same state as that in Fig. 22.

Fig. 24.



The horizontal thrust of a roof is nothing more than a particular case, to which the foregoing rules apply. The equation in Art. 36 is given in words at length, with an example of its application to that purpose.

40. *Rule for the Horizontal Thrust of an Inclined Beam.*—Multiply the weight in pounds by the cosine of the angle of inclination; and multiply this product by the distance, in feet, of the centre of gravity from the lower end; divide the last product by the height D E in feet, and the quotient will be the horizontal thrust in pounds.

Example.—Let the weight diffused over the length of a rafter be 1600 lbs.; the angle of inclination 27 degrees, of which the cosine is ·891; and the distance of the centre of

gravity from the lower end, 7 feet; the rise or height D E being 6 feet 6 inches, or 6·5 feet.

Then, $\frac{1600 \times \cdot 891 \times 7}{6 \cdot 5} = \frac{9979 \cdot 2}{6 \cdot 5} = 1534$ lbs. nearly for the horizontal thrust, which is not much less than the weight in this particular case.

When the centre of gravity is at the middle of the length of the rafter, the rule becomes more simple, and may be stated as follows:—

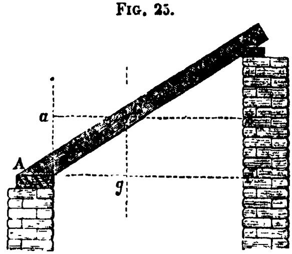
Rule, when the centre of gravity is at the middle of the length of the rafter or beam. Multiply the weight in pounds by the distance A E, in feet (which in a roof is half the span), *and divide the product* by twice the height D E, in feet, and *the quotient* will be the horizontal thrust.

Example.—The weight uniformly distributed over a rafter is 200 lbs.; the span of the roof is 20 feet, half of which is 10 feet; and the height of the roof is 5 feet. Then, $\frac{200 \times 10}{2 \times 5} = 200$ lbs. the horizontal thrust, which is exactly the same as the weight, and will always be so when the roof rises one-fourth of the span, but not in other cases.

41. Let us now suppose a weight to be laid on at D, in Fig. 24; its effect would be to press the beams in the directions of their lengths, as has been shown, and the magnitudes of these pressures may be found by the former articles (see Arts. 6 and 14). Hence we see that a beam performing the part of *a strut or an oblique support is often strained by two forces, the one being caused by the weight supported, and the other* by the weight of the beam itself, or some uniform load. But it is a well-ascertained fact, that a beam pressed in the direction of its length is very much weakened by a cross strain of this kind. If a beam happens to have a slight natural curvature the convex side should be placed upwards, which will counteract the effect of the weight of the beam.

42. It is easy to alter the directions of the pressures of a beam by altering the position of the supporting surfaces. If, for example, the beam A B (Fig. 25) were cut so as to rest upon two level plates at A and B, the beam would have no tendency whatever to slide, notwithstanding its inclined position, and consequently it would have no horizontal thrust. The carpenter may in many cases take advantage of this circumstance in preventing oblique strains upon the points of support, for those supports may be abundantly strong to resist a perpendicular pressure, and yet be incapable of sustaining a very small force in an oblique direction.

FIG. 25.



The present example shows that by cutting the rafters of a shed roof so that they may rest level upon the plates, the roof will have no tendency to push out the lower wall.

43. To find the perpendicular pressure upon the points of support, draw the horizontal line $a\,b$ through G the centre of gravity of the beam.

Then, $\dfrac{W \times b\,G}{a\,b}$ is equal to the pressure on A,

And, $\dfrac{W \times a\,G}{a\,b}$ is equal to the pressure on B;*

Or, as b G : a G : : pressure on A : pressure on B.

The perpendicular pressures upon the points of support when the beam is horizontal, as in Fig. 26, may be found by the same rules.

FIG. 26.

When two or more weights are unequally distributed, the

* Gregory's 'Mechanics,' vol. i., art. 80.

pressure on each point of support is equal to the sum of the pressures of each weight taken separately and found as above.

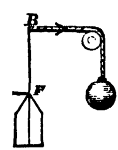
OF THE STRAIN UPON BEAMS LAID HORIZONTALLY.

44. As the principle of the composition and resolution of forces enables the carpenter to determine the direction of the strains on a beam or combination of beams according to position, the application of the principle of the lever will enable him to ascertain the strains within the beam itself as well as the resistance which it offers to these strains.

45. Let A F B (Fig. 27) represent a lever in which F is a fixed point, usually called the fulcrum, on which it can move freely. To balance the lever on the point F, each arm should be loaded in the inverse ratio of the horizontal distance of the centre of gravity of the load from F; that is to say, the lighter load should be placed on the longer arm, and the heavier load on the shorter arm, and the loads should be so proportioned that the lighter multiplied by the longer arm should be equal to the heavier multiplied by the shorter

FIG. 27.

FIG. 28.



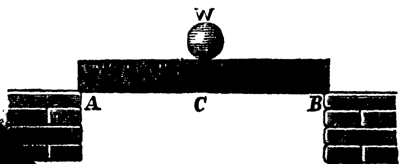
arm. The results so found are called the *moments* of the loads or forces about the point F. No difference would be caused in this relation if the lever were bent or cranked, as in Fig. 28, and the force at B, caused by a weight moving over a pulley, or by any other equivalent force whatever. In applying the principle of the lever to determine the strength to beams and girders, the moment of the load is usually

called the *moment of rupture*, and sometimes the bending moment, and that of the forces tending to prevent rupture is called the *moment of resistance.*

46. A beam projecting from a wall (Fig. 29) may be considered as a lever, in which the length A F is one arm, and the depth F B the other arm, the load at A being resisted by the strength of the fibres of the beam between F and B. The moment of rupture M of a beam in this position is therefore $W \times AF = M$; and generally, the moment of rupture at any section C is equal to the load multiplied by the distance of its centre of gravity from that section.

FIG. 29.

FIG. 30.



47. [illegible] placed on two supports (Fig. 30) and loaded on the middle, the moments will be the same as in two bent levers meeting at C, the long arms of which are A C and C B, the short arms being the depth of the beam, as in Fig. 29.

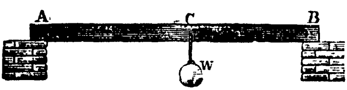
It will make the application of the principle of the lever more clear to the reader, if instead of the weight at C we assume that each support presses the beam upwards at A and B with a force equal to half the weight when the centre of gravity of the load is at the middle of the beam; it will then be easily seen that the moment tending to cause rupture at C is equal to *half the length* of the beam, or A C multiplied by half the load W; or $M = \dfrac{W \times AB}{4}$.

48. When a beam is laid in a horizontal position, as in Fig. 26, and a load is uniformly distributed over its length,

or the beam is only loaded by its own weight, the strain upon the beam is the same as if half the weight were acting at its centre of gravity.

But if the weight be distributed over the beam it must be of a yielding nature, otherwise this rule will not hold good. If a strong short beam be laid upon the first beam, and the weight upon that, the strain upon the lower beam would be removed to the points where the ends of the short beam would rest upon the longer one, and the effect of the weight on the longer one would be decreased.

49. When a beam is supported at the ends, as in Fig. 31, the stress arising from any weight, W, produces the greatest strain when it is applied in the middle of the length. When the load is placed at C (Fig. 31) the strain or moment of rupture at that point will be equal to the portion of the weight on either of the points of support (as found by Art. 43) multiplied by the distance of the weight W from that point of support, or $M = \frac{W \times AC \times BC}{AB}$.



And, if w be the greatest weight the beam would support in the middle, the greatest weight W that it could support at any other point C, will be found by the following proportion:

As the distance A C multiplied by the distance B C,
Is to the square of half the length of the beam;
So is the weight w, that could be supported in the middle,
To the weight W that could be supported at the point C.

For if M_1 be the moment caused by the weight w

$$w\left(\frac{AB}{2}\right)^2$$

$$\text{but } M_1 = M \text{ and } W \times \frac{AC \times BC}{AB} = w \times \frac{AB}{4}$$

$$\therefore\ W \times AC \times BC = w\left(\frac{AB}{2}\right)^2$$

$$\therefore\ AC \times BC : \left(\frac{AB}{2}\right)^2 :: w : W.$$

From whence it appears, that a beam 20 feet long will bear double the weight, at 3 feet distance from one end, that it would bear in the middle of its length. Consequently the farther a load can be removed from the middle of the beam the better; and when it is necessary to place the stress at or near the middle, it is of great importance to cut the timber as little as possible with mortises at the point where the stress acts, and the piece should be as free as possible from knots in that point.

50. If w be the greatest weight a beam whose length is L will support in the middle, and the beam be required to support a greater weight W, the maximum distance at which it may be placed from the ends of the beam is

$$\frac{L}{2}\left(1 \pm \sqrt{\frac{W - w}{W}}\right)$$

= the distance of the point C from the ends. The positive sign gives the distance from one end, and the negative sign gives the distance from the other end.

For we have (Art. 49)

$$\frac{w}{W} = \frac{AC \times BC}{\left(\frac{L}{2}\right)^2} = \frac{(L - BC) \times BC}{\left(\frac{L}{2}\right)^2}$$

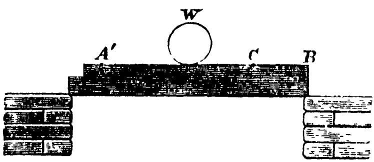
$$BC \times L - BC^2 = \left(\frac{L}{2}\right)^2 \times \frac{w}{W} - \left(\frac{L}{2} - BC\right)^2 = \left(\frac{L}{2}\right)^2 \times \left(\frac{w}{W} - 1\right)$$

$$\text{and } BC = \frac{L}{2}\left(1 \pm \sqrt{\frac{W - w}{W}}\right).$$

51. The moment produced in any point C of a beam by a

load W placed half way between the supports (Fig. 32) is equal to one-half of the weight multiplied by the distance B C from the nearest pier, *i.e.*

FIG. 32.



$$M = \frac{W \times BC}{2}.$$

52. If the load W be removed to C (Fig. 32), the moment of rupture at any other point A′ will be equal to the weight multiplied by its distance from the pier B and by the distance of the point A′ from the other pier A, and divided by the total length of the beam, or

$$M = \frac{W \times CB \times AA'}{AB}.$$

53. The moment at any point arising from two or more weights placed on a beam supported at both ends is equal to the sum of the moments in that point found for each weight separately. (Art. 52.)

OF THE EQUILIBRIUM OF AN ASSEMBLAGE OF BEAMS.

54. When an opening is too wide to be spanned with one or two pieces of timber, it may sometimes be effected by a combination of pieces which bear some resemblance to an arch in masonry; the principles of stability are not, however, exactly the same. In carpentry stability is gained chiefly by the resistance of the material to stretching and compression, and the mode of connection. In a stone arch it is attained by a proper disposition of the parts, so that each may be retained in its place by pressure alone, but in carpentry to lose the advantage of connection is to lose that in which the excellence of the carpenter's art chiefly consists.

Of the Points of Fracture in a System of Framing.

55. The balance of the parts in a system of framing is not so complicated a question as it is generally imagined to be; at least it is not so while our inquiries are confined to practical cases. A system of framing for spanning a wide opening is generally composed of two equal and symmetrical parts; and when it is loaded, the load is also similarly disposed. When the parts are loaded so as not to be in equilibrio, the system will divide itself into four parts only, and not more.

56. Again, if the system be balanced, and rupture be produced by a weight laid on at any particular point, the system may either divide itself into three or four parts. When the weight is laid upon the system at or near the middle of the span, it will divide itself into four parts. When the weight is laid upon it at some distance from the middle, the framing will generally divide itself into three parts.

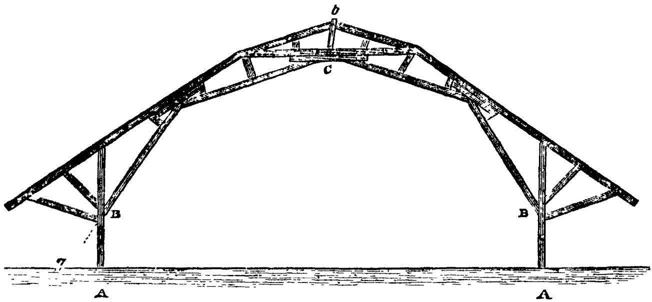
57. Let Fig. 33 represent a system of framing, which is similar to one applied by Mr. Seppings for the roof of a dock for building ships under cover.* The parts of this roof are obviously not in equilibrio, and the weight of the roof itself tends to cause fracture at the points B, C, and B′, consequently to break the roof into four parts, A B, B C, C B′, and B A′.

The uprights A B and A′ B′ have neither position nor weight to balance the spread of the superior parts; and the stability of the system depends wholly on the strength of the post to resist a cross strain, and the connection of the parts. By a proper disposal of the parts of this roof, the greater part of the strain arising from the weight of the roof itself might

* The roof designed by Mr. Seppings is 95⅓ feet span from A to A′; it is described in the 'Encyclopaedia Britannica,' art. Dock.

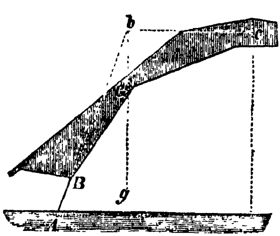
have been removed; and of course the roof would be much stronger to resist any other force, such as the wind, &c.; or

FIG. 33.



it might have been constructed with less material and labour. This example has been cited to show that it is as essential that the principles of equilibrium should be known, as it is to understand the best method of stiffening and connecting the parts. The roof of Mr. Seppings is a fine example of the latter, and it has undoubtedly been for the purpose of leaving as much free space as possible that the upright posts only were used; for an oblique strut in the direction *a* B would have added much to the stability of the frame.

FIG 34.



58. To find the position of the side posts so that the roof may be in equilibrio. Let G be the centre of gravity of that part of the frame between B and C (Fig. 34). Draw the vertical line *b g* through G, and from the middle of the depth of the framing at C draw the horizontal line C *b*, cutting the vertical line in *b*. Then draw the line A B *b*, and A B is the position of the post.

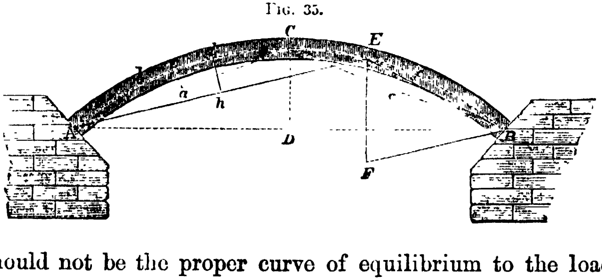
Here no notice is taken of the weight of the post itself, because it is too small to produce a sensible difference in the position.

59. In Fig. 33, B, C, and B′, may be called the points of fracture, or the centres of motion, which in this case are easily found by inspecting the figure. In general it is more difficult to ascertain their position, and they are affected by so many circumstances, that it is not practicable to give a general rule for finding them.

But in most cases the positions of the centres of motion may be determined, with all the accuracy required in practice, by inspection; and it may be as well to illustrate this point before proceeding to examine these combinations further.

In the first place, suppose A C B (Fig. 35) to be a solid curved beam, resting on the abutments A and B. Let it be uniformly loaded and the strength equal in every part of its length, then the neutral line would be at the middle of the depth. Now if the curvature of the neutral line

FIG. 35.



should not be the proper curve of equilibrium to the load, there would be a tendency to break at three points, one of which would be at C, the middle of the length. The other points would be near where the neutral line is most distant from the chord line A C and C B, but a little below, that is, at e and f in the figure.

60. If the beam should be much weaker at any point *b* than it is at *e*, the centre of motion would be in the point *b*, and one of the fractures would be there in the case of failure. But if the weak point were at *d*, the beam would be less liable to fail there, unless it should be very much weaker than at *e*.

61. Again, considering the strength to be equal throughout, and the load to increase from A and B towards C, then the fractures would take place at, or rather above the points *e* and *f*. On the contrary, if the load should increase from C towards A and B, the fractures would be below the points *e* and *f*.

Hence, by attending to the form, the strength of the parts, and the disposition of the load, in a system of framing, the centres of motion or places of fracture may be determined with all the accuracy that is necessary in practice.

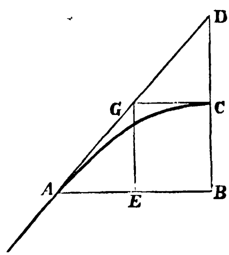
62. But the constant load on a system of framing may be so balanced, that it will have no tendency to produce fracture; and the strength should be such, that any other load of a variable nature, as the weight of carriages, &c., upon a bridge, or the like, may also be supported. In order that the load may be thus balanced, the form of the supporting frame should be arranged, that the line or curve of equilibrium, which is in the direction of the resultant of the forces, may pass through or near the middle of the depth of every part.

When the nature of the load is known, the form of the curve of equilibrium may either be found by mathematical investigation, or by mechanical means.

TO DETERMINE THE CURVE OF EQUILIBRIUM.

63. Let A C represent a portion of a curve of equilibrium (Fig. 36), C being the vertex of the curve, and G E a vertical line passing through the centre of gravity of the load resting upon the part between A and C.

FIG. 36.



Then by similar triangles A E : G E (= C B) :: A B : B D :: horizontal thrust to the weight. Therefore, $\frac{\text{C B} \times \text{A B}}{\text{A E}} = \text{B D}$. But B D is the subtangent of the curve, consequently when it agrees with that of any known curve, that curve is the curve of equilibrium.

64. *Example* 1.—Suppose the load to be uniformly distributed over the framing, then the centre of gravity of the load over any portion A C will be over the middle of A B, and A E will be equal $\frac{1}{2}$ A B. Consequently, B D = 2 B C, a property of the parabola. Therefore when the weight is uniformly distributed the curve of equilibrium is a parabola. A simple method of describing a parabola will be found in the section on Roofs. Various other methods are given by writers on Conic Sections; particularly in Emerson's 'Conic Sections,' book iii., props. 59 and 60; and an easy method is given by Nicholson in his 'Carpenter's Guide,' p. 11.

As in bridges and roofs the weight is very nearly uniformly distributed, it will generally be near enough for practice to use the parabola as the curve of equilibrium; where greater accuracy is required, it may be found by Art. 68.

65. *Example* 2.—Let the weight on any part of the framing be proportional to its distance from C, the middle of the span.

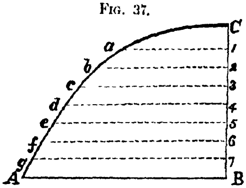
Then the distance A E will be equal to $\frac{1}{3}$ A B· because

the distribution of the weight may be represented by a triangle, with the vertex at C, and base at A B. In this case B D = 3 B C, a property of the cubic parabola. Hence, when the weight is distributed in proportion to the distance from the centre, the curve must be a cubic parabola. To describe this curve, put s = half the span, and h = the rise of the framing; x the absciss, and y the corresponding ordinate. Make $x = n\,h$; then $s\,n^{\frac{1}{3}} = y$.*

The curve may also be constructed by the following method:—

Divide the rise B C (Fig. 37) into eight equal parts, and draw the horizontal lines a 1, b 2, c 3, &c. Then the distance

FIG. 37.



A B multiplied by	0·5	will be equal	a 1,
A B	,,	0·63	,,	b 2,
A B	,,	0·721	,,	c 3,
A B	,,	0·7937	,,	d 4,
A B	,,	0·855	,,	e 5,
A B	,,	0·9085	,,	f 6,
A B	,,	0·956	,,	g 7.

Through the points a, b, c, d, e, f, g, draw the curve, and it will be the cubic parabola sufficiently near for practice.

66. Whenever the distance of the centre of gravity from A (Fig. 36) is expressed by the equation A E = $\frac{1}{m}$ A B, the curve of equilibrium will be a parabola of which the equation will be $a\,x = y^m$, and the subtangent = mx.†

67. It is useful to know the subtangent of the curve of equilibrium, because it gives the tangent, and consequently the direction of the pressure at the abutment. In any case,

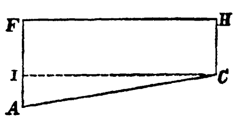
* For by the property of the curve, $a\,x = y^3$; and when $x = h$, and $y = s$, $a\,h = s^3$, or $a = \frac{s^3}{h}$; therefore $\frac{s^3\,x}{h} = y^3$, or $s\left(\frac{x}{h}\right)^{\frac{1}{3}} = y = s\,n^{\frac{1}{3}}$, when $x = n\,h$.

† Emerson's 'Fluxions,' p. 203.

where the equation of the curve of equilibrium is $a x = y^m$, the pressure on the abutment will be in the direction of a line, which makes an angle with the horizon, of which the tangent is $\frac{m h}{s}$; where s = half the span, and h = the rise. And also, when we make w = the weight of half the framing, we have $\frac{s w}{m h}$ = the horizontal thrust.

68. *Example* 3.—When the weight is distributed over a piece of framing, a bridge for example, so that the weight on any portion from the middle towards the abutment shall be represented by a trapezoid A F H C (Fig. 38), put H C = a which will represent the weight at the middle of the arch; and let I C : I A :: 1 : n; then $a y + \frac{1}{2} n y^2$ = the weight on any portion of the arch, whose horizontal ordinate is y.

FIG. 38.



Put A B = y (Fig. 36) and C B = x, and we have $\frac{3 x (n y + 2a)}{n y + 3 a}$ = B D the subtangent of the curve. Consequently, when the point A is at the abutment, and $y = s$ = half the span, and $x = h$, we have $\frac{3 h (n s + 2 a)}{s (n s + 3 a)}$ = tangent of the angle which the direction of the pressure on the abutment makes with the horizon. And $\frac{s^2}{6 h} (3 a + n s)$ = the horizontal thrust at the abutment.

The curve may be constructed from its equation

$$\frac{y^2}{2 \mathrm{H}} (a + \tfrac{1}{3} n) = x,$$

in which H is equal to the horizontal thrust.

This equation will be sufficiently accurate for determining the form of the curve for most cases; as the expression for

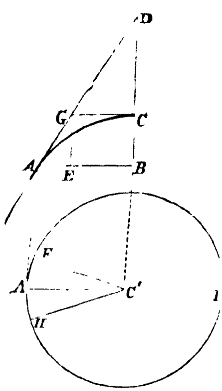
the weight will nearly agree with the distribution most commonly occurring in practice. The absciss x, and ordinate y, become h, and s, at the abutment, and these being always given, we have H $\frac{s^2}{2h}(a + \frac{1}{3} n s)$; and, H being determined, the ordinates of the curve may be easily calculated.

The curves that apply to such cases as usually occur in practice are evidently of a parabolic kind; and the same observation applies to those curves which are proper for cupolas, or domes, to which we must now proceed.

To determine the Curve of Equilibrium for a Cupola or Dome.

69. Conceive the dome to be generated by the motion of the curve A C (Fig. 36) round C B an axis; then the same relations will obtain as in the case of an arch (Art. 63), that is $\frac{CB \times AB}{AE} = BD =$ the subtangent of the curve of equilibrium. Let A I be the plan of the dome (Fig. 39), and let it be divided at the circumference into any number of equal parts, of which H F is one; then, whatever form is necessary to equilibrate the sector H F C′, must be equally requisite for every other part of the dome. Let A C B be a section through A′ C′ the middle of the gore H F C′.

Fig. 39.



70. *Example* 1.—When the weight is uniformly distributed. In this case the weight on any part of the gore is proportional to the distance from the centre; consequently, the

centre of gravity is $\frac{1}{3}$ A B from A: and the curve is a cubic parabola, the same as in Example 2, Art. 65; and may be described in the same manner.

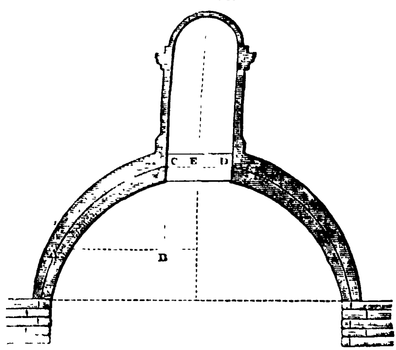
71. *Example* 2.—Let the weight be distributed so that the weight on any portion A C (Fig. 39) is $= y\,a + \frac{\pi\, b\, y^3}{3}$, where y is equal the ordinate A B, a the depth of an uniform weight; and $1 : b$ the ratio of increase of another part of the load, which increases regularly from the centre to the circumference: also $\pi = 3 \cdot 1416$.

And as in Art. 68, we obtain $x = \frac{y^2}{2\,\mathrm{H}}(a + \frac{1}{3}\pi\, b\, y^2)$; where x = B C the absciss; and H = the horizontal thrust.

Hence, when the rise and radius of the base of the dome are given, the rise or height being h, and the radius r, $\frac{r^2}{2\,h}(a + \frac{1}{3}\,\pi\, b\, r^2) = \mathrm{H}$.

The most useful cases of domes will be determined by this equation, from which it is easy to find a sufficient number of points in the curve to design the framing upon. It is scarcely necessary to remind the reader that in domes, as in arches, the curve of equilibrium must pass through the middle of the framing.

FIG. 40.



72. *Example* 3.—Suppose the curved part of the dome (Fig. 40) to be uniformly loaded, and a lantern on the top, the space C D being open.

Let W be the weight of the lantern, and $w\,\pi\, y\,(y + r) =$

the weight pressing on the curved surface $A\,C$, where $y = A\,B$, $r = C\,E$ the radius of the lantern.

The whole weight is $w\,\pi\,y\,(y + r) + \mathrm{W}$, and the equation of the curve of equilibrium is

$$\frac{y}{\mathrm{H}}\left(\tfrac{1}{3}\,w\pi y^2 + \tfrac{1}{2}\,w\pi r y + \mathrm{W}\right) = x.$$

Let the radius of the base of the dome be $\mathrm{R} + r$, and h the height of the base of the lantern. Then,

$$\frac{\mathrm{R}}{h}\left[w\pi\left(\tfrac{1}{3}\,\mathrm{R}^2 + \tfrac{1}{2}\,\mathrm{R}\,r\right) + \mathrm{W}\right] = \mathrm{H} = \text{the horizontal thrust.}$$

73. From the equations in the two preceding articles, the proper curve for a dome may be obtained; but it may be remarked, that so long as the curve is not more convex towards the external surface than the proper curve of equilibrium, the form may be changed at pleasure; because every part of the framing may be strutted so that it cannot press inwards.

The curve of equilibrium is not the weakest form for a dome, as Dr. Robison states it to be,* but it is the limit that should never be exceeded. The curvature of the line passing through the middle of the framing may be of any form within the middle, and be stronger; but if it be without the dome, it will be weaker.

From the mutual tendency of the parts to the axis, a dome admits of an opening in the centre; but it is not a matter of indifference whether the weight be omitted or not in determining the curve of equilibrium. The reader will, however, easily perceive that the external covering may have any form that is most consistent with the other parts of the building, as these calculations refer to the supporting frame only. The strongest forms are generally the most beautiful, but the consideration of beauty of form does not come within the plan of this work.

* 'Encyclopædia Britannica.'

General Observations on Designing, Framing, &c.

74. The principal questions relative to the action of forces on single beams, and on systems of framing, have now been considered; and it only remains to make a few remarks on the best method of applying those principles so as to form a perfect design.

In the first place, the artist must remember "that the strength of a piece of framing, whatever may be the design, can never exceed that of its weakest parts; and that partial strength produces general weakness."*

Therefore, let the fixed conditions, or those parts which cannot be altered, be well considered; and as far as it can be done, let them be drawn correctly to a scale; showing the curves of equilibrium, the points where the forces act, and every other particular condition. Also, it must be considered whether the forces are to act constantly on the same parts, or to be subject to changes; and the nature and extent of these changes should be exhibited.

2ndly. The nature of the sustaining points should be carefully examined, whether they be capable of resisting a force acting obliquely against them or not; and the framing must be disposed accordingly.

Then a design may be sketched in, of such a nature as shall appear best adapted to attain the objects in view; the strength of the parts being fixed by the rules in the next section.

Nothing will assist the artist more in forming a good design than just conceptions of the objects to be attained; and nothing will render those objects more familiar to his mind than drawing them.

* Seppings' 'Philosophical Transactions.'

SECTION II.

OF THE RESISTANCE OF TIMBER.

75. To know the resistance which a piece of timber offers to any force tending to change its form, is one of the most important species of knowledge that a carpenter has to acquire: and to be able to judge of the degree of resistance from observation only, even in common cases, requires nothing less than the practice of a life devoted wholly to carpentry.

Besides, it is a kind of knowledge that is confined to the person who has obtained it, and dies with him. It is a feeling of fitness that cannot be communicated, nor yet described; nevertheless it is a feeling that every thinking practical man is sensible he possesses. The author is far from having a wish to banish the nice observation that gives birth to this feeling; because it is more desirable that it should be encouraged than suppressed; but there are cases where it fails,—that is, when the magnitude of the object is beyond the range of ordinary practice, and where new combinations are attempted. In such cases the laws of the resistance of solids should be referred to, even by the expert practical man; and he will be better able to judge of their correctness if he finds them, in common cases, to give results that agree with the conclusions he has drawn from practice.

But there are many, besides practical carpenters, that ought to know something of the principles of building, and who have not an opportunity of becoming acquainted with those principles through practice; to such persons the rules

and experiments detailed in this work will be found extremely useful.

In order to determine the dimensions or scantling of a piece of timber, that shall be capable of sustaining a given weight or pressure, the laws that regulate its resistance should be considered; and to accomplish this in a manner that is likely to be useful, we must consider what effect is produced when a piece of timber is overloaded. This effect, in general, is nothing more than a certain degree of flexure, or bending, as it seldom happens that timbers are absolutely broken; and generally, a small degree of bending renders a beam unfit for its intended purpose.

Much has been said on the irregular nature of timber, and that it is impossible to make rules or tables for scantlings on that account; but it must be observed that these remarks apply only to rules for the strength of timber to resist breaking; and even in that case timber is not so irregular as is generally imagined. The difference in good timber is still less perceptible when the bending only is considered, and the laws relating to flexure are founded on experiments of an unexceptionable character. It has been shown in the preceding section (Art. 18) that a change in the position of the resisting parts brings new forces into action, which is the cause of the irregularity observed by Buffon in his experiments;* but in a piece of carpentry these changes must never be so great as to produce a sensible effect; therefore it would be an useless refinement to attempt to form rules that would embrace all the circumstances these changes produce; besides, it would render them too complicated to be useful.

In all cases timbers that are exposed to considerable strains ought to be of a good quality; therefore the data should be drawn from experiments on good timber, and not

* 'Mémoires de l'Académie des Sciences,' 1741, pp. 328–332.

from inferior specimens. For if inferior specimens were made the basis of calculation, at what point of inferiority should we begin? and how should it be described so as to enable us to compare it with any other timber? But when it is known what a piece of good timber will do, it will be easy to compare its description with that to be used. Good timber is that which is perfectly sound, straight grained, free from large knots or other defects, particularly near the strained points, and seasoned. Specimens of this kind are marked *medium* in the Tables of Experiments. In another Section the reader will find further information respecting the nature and qualities of different kinds of timber.

But the qualities even of good timber vary in some degree according to the nature of the soil, and the dryness and exposure of the situation where it was grown. The age of trees at the time of cutting, the natural defects, such as knots, shakes, &c., also the mode of seasoning, or the comparative dryness, is the cause of some difference in the strength and stiffness of timber: all these things considered, it is impossible to calculate correctly its strength and stiffness. But, fortunately, that precision which is so essential to the philosopher, is not absolutely necessary to the architect and engineer. They content themselves with approximations that are simple, and more easily obtained; and, provided that the limits which cannot be passed with safety be pointed out, these approximations are sufficient to direct their practice.

Definitions, and General Principles.

76. The laws of the resistance of materials depend on the manner in which the pieces are strained, and may be divided into three kinds.

First, When the force tends to pull the piece asunder in direction of its length, or the *resistance to tension.*

Secondly, When the force tends to break the piece across, or the *resistance to cross strains.*

Thirdly, When the force tends to compress the body in the direction of its length, or the *resistance to compression.*

77. *Stiffness* is that property of bodies by which they resist flexure or bending. *Strength* is that by which they resist fracture or breaking. This distinction must be carefully attended to, because the laws of strength and stiffness are not the same. For instance, the stiffness of a cylinder, exposed to a cross strain, increases as the fourth power of the diameter, but the strength increases only as the cube of the diameter. If the diameter of a cylinder be doubled, its stiffness will be sixteen times as great, but its strengh will only be increased eight times.

In carpentry the comparative stiffness is of much greater importance than the comparative strength, as timbers are seldom exposed to strains that break them.

78. All bodies may be extended or compressed; and the extension or compression is assumed to be directly as the force producing it: that is, if a force of 100 lbs. produces an extension of one-tenth of an inch, 200 lbs. will produce an extension of two-tenths of an inch, and so on. It is on the truth of this principle that the greater part of the following inquiry depends; and it has been found by experiment to be practically true up to a certain point called the *limit* of elasticity, which, according to Barlow's experiments on the transverse strength of timber, would appear to be about *one-third*, and according to Kirkaldy's experiments on wrought iron, about *one-half* of the force required to produce rupture.

When this limit is exceeded, the alteration in length is no longer in proportion to the load, but increases as the ultimate strength of the material is approached; a permanent change then takes place, and when the load is removed the beam or bar will not quite return to its original state; this

is called the *set*. The subject is still involved in obscurity, particularly as regards materials strained in the direction of their length. Barlow ('Essay on the Strength of Timber') states that he left more than *three-fourths* of the breaking weight hanging from a piece of timber for twenty-four hours without perceiving the least change in the state of the fibres or any diminution of the ultimate strength: in wrought iron a very decided change takes place under a corresponding application of the load, and Hodgkinson has shown that a permanent alteration takes place when a very small proportion of the breaking weight is applied.

Recent experiments on direct cohesion and on transverse strength seem to show that the theory of the resistance of materials is still in an unsatisfactory state.

It is probable, from observation and the few experiments we are in possession of, that the limit of elasticity is reduced by time; and it may be assumed in reference to a beam of timber submitted to a cross strain when loaded to within *one-fifth* of its breaking weight, that in the course of time the elasticity will be so impaired as to produce a permanent set.

ON THE RESISTANCE TO TENSION.

Of the Stiffness of Bodies when strained in the Direction of their Length.

79. When wood is strained in the direction of its length and within the so-called elastic limit of the material, the elongation produced by the strain is nearly in direct proportion to the straining force and original length, and inversely as the area of the cross section.

Let L represent the original length in *inches*, l the amount of elongation also in inches, W the weight in lbs., S the sectional area in square inches, and E the *Modulus* of *Elas-*

ticity, or weight in lbs. per square inch required to extend the piece to double its original length, on the assumption that the rate of extension throughout is uniformly as the weight. Then, $\frac{L \times W}{E \times S} = l.$ [1]

From which the following rule is obtained.

Rule I.—Multiply the weight in lbs. to be suspended by the length of the piece in inches, and the product divided by the sectional area in square inches, multiplied by the value of E, Tables I. and II., will give the elongation in inches; or the same product divided by the value of E multiplied by the amount of elongation that would leave the elasticity of the piece uninjured, and the result will give the area of the section in square inches.

80. Table I.—Of the Modulus of Elasticity from Various Sources.

	Value of E in lbs. per square inch.
Box	1,856,000
Chestnut, dry	1,147,500
Fir, Baltic	1,823,000
,, New England	1,328,000
Larch	1,363,500
Mahogany	1,424,250
Oak, English	1,714,500
,, Dantzic	1,998,000
Pine, Pitch	1,252,200
,, Red	1,840,000
,, Yellow, American	1,600,000
Teak, Indian	2,167,074
Iron, Wrought	22,400,000
,, Cast	17,000,000

The timber from which the following experiments were made was grown in the Department of Vosges, in France, and appears to have been of less strength than that used in other experiments.

TABLE II.—From the EXPERIMENTS of MM. CHEVANDIER and WERTHEIM.*

Description of Wood.	Specific Gravity.	E Modulus of Elasticity per square inch.	Load corresponding to the Limit of Elasticity per square inch.	Force per square inch capable of producing Rupture.
		lbs.	lbs.	lbs.
Acacia	·717	1,794,812	4,534	11,279
Fir	·493	1,583,314	3,062	5,945
Hornbeam	·756	1,543,632	1,823	4,253
Birch	·812	1,418,326	2,300	6,116
Beech	·823	1,394,432	3,295	5,078
Oak (pedunculata) ..	·808	1,390,734	..	9,231
,, (sessiliflora) ..	·872	1,311,086	3,341	8,050
Pine (silvestris) ..	·559	802,324	2,323	3,627
Elm	·723	1,657,417	2,620	9,942
Sycamore	·692	1,655 283	1,620	8,761
Ash	·697	1,594,977	2,772	9,643
Alder	·601	1,576,061	1,594	6,457
Aspen-tree	·602	1,530,262	1,472	10,240
Maple	·674	1,452,746	1,519	5,092
Poplar	·477	735,618	1,432	2,802

The elastic limit was assumed to have been attained when the permanent set was $\frac{1}{20000}$th part of the original length.

OF THE STRENGTH OF A BEAM TO RESIST A STRAIN IN THE DIRECTION OF THE LENGTH.

81. The weight that will produce fracture is in proportion to the area of the section, multiplied by the weight that would fracture a unit of that area.

The following Tables contain the results of the chief experiments which have been made on the direct strength, and show the weight that will destroy the cohesive force of one square inch.

* Morin, 'Résistance des Matériaux.'

Table IV.—Cohesive Force of Different Woods. (B. Bevan, 'Phil. Mag.' 1826.)

Description of Wood.	Spec. grav.	Cohesion of a sq. inch.	Description of Wood.	Spec. grav.	Cohesion of a sq. inch.
		lbs.			lbs.
Acacia	·85	16,000+	Larch	·57	8,900
Apple	·71	19,500	Lignum vitæ ..	1·22	11,800
Ash	·84	16,700	Lime-tree ..	·76	23,500+
,, ...	·78	19,600	*Mahogany* ..	·87	21,800+
Beech	·72	22,200	,, ..	·80	16,500
Birch	·64	15,000−	Maple	·66	17,400
Box	·99	15,500−	Mulberry ..	·66	10,600
Cane	·40	6,300	Oak, English ..	·70	19,800+
Cedar	·51	11,400	,, ,, ..	·76	15,000
Chestnut (Horse)	·61	12,100−	,, ,, old	·76	14,000
,, (Sweet)	·61	10,500−	,, pile out of river Cam ..	·61	4,500
Damson .. .	·79	14,000	,, black bog	·67	7,700−
Deal, Norway spruce	·34	18,100+	,, Hamboro.	·66	16,300+
,, ..	..	17,600+	,, ,,	·66	14,000
,, Christiana	·46	12,400	Pine, Petersburgh	·55	13,300−
,, ,, ..	·46	12,300	,, Norway ..	·59	12,400−
,, ...	·46	11,000	,, ,, ..	·66	14,300
,, English ..	·47	7,000	,, Petersburgh	·55	13,100+
Elder	·73	15,000	Plane	·64	11,700−
Elm	·69	14,400	Poplar	·36	7,200−
Hawthorn ..	·91	10,700	Sally	·70	18,600+
,, ...	..	9,200	Sycamore ..	·69	13,000
Hazel	·86	18,000+	Teak, old ..	·53	8,200
Holly	·76	16,000	Walnut	·59	7,800
Hornbeam ..	·82	20,240+	Willow	·39	14,000
Laburnum ..	·92	10,500	Yew	·79	8,000
Lancewood ..	1·01	23,100+			

Note.—The specimens in the above Table varied in length from 9 to 13 inches, and were reduced in a lathe for a small part of the length, in the middle, to near half an inch in diameter, leaving at each end something more in general than 4 inches long, and about $\frac{11}{16}$ inch in diameter, for the purpose of being fastened into cast-iron boxes, made of sufficient strength to bear a strain of several tons weight. The wood thus prepared was secured at each end in one of these iron boxes, and suspended vertically at the end of a lever of suitable strength to bear a force of 5000 or 6000 lbs., the operating strain being produced by the gradual and slow motion of weights of 200 lbs. each, resting occasionally at intervals of 5, 10, 15, or 20 minutes, and sometimes for hours.

In the course of these experiments Mr. Bevan occasionally found part of the larger ends drawn out in a cylindrical shape when the lateral adhesion was less than the longitudinal cohesion; in these cases the number of pounds expressive of the cohesion is short of what is due to

83. Table V.—Cohesion of a Square Inch pulled asunder in a Direction perpendicular to the Length of the Fibre.

Kinds of Wood.	Cohesion of a square inch perpendicular to Fibres, in lbs.	Experimentalist.
Oak	2316	Tredgold.
Poplar	1782	,,
Larch { from ..	970	,,
Larch { to	1700	,,
Scotch fir	562	Bevan.
Memel ,, { from	540	,,
Memel ,, { to ..	840	,,

84. Rule II.—To ascertain the load that would fracture a beam of wood strained in the direction of the length—Multiply the area of the least cross section of the piece in inches by the weight that will tear asunder a bar an inch square of the same material—Tables II., III., and IV.—and the product will be the weight in pounds. The load upon a square inch should never exceed one-fourth of that which would cause rupture, and in many cases it should be less—see Art. 78.

ON THE RESISTANCE TO CROSS STRAINS.

Of the STIFFNESS of Beams to resist Cross Strains.

85. When a weight is laid upon the middle of a piece of timber that is supported only at the ends, it always causes some amount of deflection. When the piece bends in a very small degree, it is said to be stiff, and when the bending is considerable, it is called flexible.

the specimen, and in the Table these are distinguished by +. On the other bearing sometimes the specimen broke during the motion of the weight, and therefore would have separated under a less force, with more time; these are marked −.

The stiffness of beams of the same length is proportional to the space through which they are bent by a given weight. That two pieces of different lengths may be equally stiff, the deflection, or bending, should be proportional to their lengths. For a deflection of one-fourth of an inch in a joist 20 feet long would not be attended with any bad effect; but if a joist 4 feet long were to bend one-fourth of an inch, it would be totally unfit for the purpose.

Of the Stiffness of Beams supported at both Ends.

86. When a beam is supported at the ends in a horizontal position, and a weight rests upon the middle, if the deflection be of small amount, the laws regulating it may be determined as follows:—The extension of any part of the beam is directly as the force by which it is produced, Art. 79; and it is known by experiment that the deflection is in proportion to the weight, all other things being constant; therefore the deflection is as the extension. Now, the effect of a load to produce extension in a beam is as the leverage, and as the load itself; or, in other words, as the bending moment M described in Art. 44; but the leverage is proportional to the length, therefore the force producing the extension is as the length and weight directly, and the resistance to extension is inversely as the breadth, and square of the depth, as shown by writers on the Strength of Materials. But the extension of each fibre will be directly as the number of its parts extended, that is also as the length; and as the quantity of angular motion, which will again be as the length directly, and depth inversely. Uniting these equivalents of the extending and resisting forces, we find the deflection to be as the weight, and cube of the length directly; and as the breadth, and cube of the depth inversely—that is making L = the length of bearing in feet, W = the weight in pounds, B = the breadth in inches, D = the depth in inches, a = the

constant number which depends upon the nature of the material, and Δ = the deflection in inches.

We have $$\frac{L^3 \times W \times a}{B \times D^3} = \Delta. \qquad [2]$$

Before the deflection Δ can be found, the value of a must be obtained (it $= \frac{1}{40}$ of a in Tables VI. to XI.).

87. In order that the beam may be sufficiently stiff for the carpenter's purpose, the deflection should not exceed $\frac{1}{40}$ of an inch for each foot of the total length. If we substitute $\frac{a}{40}$ for a in the above formula, it becomes

$$\frac{L^3 \times W \times a}{40 \times B \times D^3} = \Delta. \qquad [3]$$

And to find a we have

$$\frac{40 \times B \times D^3 \times \Delta}{L^3 \times W} = a. \qquad [4]$$

From this formula the values of a in Tables VI. to XI. have been calculated.

88. The quantity of timber being the same, the stiffness of a beam will vary according to its depth; but there is a certain proportion between the depth and breadth, which if exceeded will render the beam liable to overturn and break sideways. To avoid which, the breadth should never be less than that given by the following rule, unless the beam be supported laterally.

Rule III.—Divide the length in feet by the square root of the depth in inches, and the quotient multiplied by the decimal 0·6 will give the least breadth that should be given to the beam.

When the depth is not determined by other circumstances, the nearer its form is made to approach that determined by the rule the stronger it will be; and, from the same rule, another is easily derived which will show the advantage of making beams deep in proportion to the thickness.

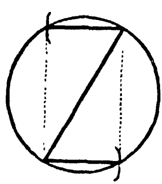
89. To find the strongest form for a beam so as to use only a given quantity of timber.

RULE IV.—Multiply the length in feet by the decimal $0 \cdot 6$, and divide the given area in inches by the product; and the square of the quotient will give the depth in inches.

Example.—If the bearing be 20 feet, and the given area of section be 48 inches; then $\frac{48}{0 \cdot 6 \times 20} = \frac{48}{12} = 4$, *and the square of 4 is 16 inches, the depth required*; and the breadth will be 3 inches. A beam 16 inches by 3 would support more than twice as much as a square beam of the same area of section; which shows how important it is to make beams deep and thin. In many old buildings, and even in new ones, in country places, the very reverse of this has been practised; the principal beams being more frequently laid on their broad than on their narrow side.

90. The stiffest beam that can be cut out of a round tree is found by laying off the thickness which is equal to half of the diameter of the circle, from the extremities of the diameter, and completing the triangles as in Fig. 41. The figure thus formed gives the breadth to the depth as 1 is to the square root of 3,* or as 1 is to $1 \cdot 732$, nearly; or as $\cdot 58$ is to 1; this being in general a good proportion for beams that have to sustain a considerable load, and where it would be impossible to get them deeper on account of the size of the tree, we may substitute it for the breadth in equation [3] which then gives for the depth :—

FIG. 41.



$$\frac{L^3 \times W \times a}{23 \cdot 2 \times \Delta} = D. \qquad [5]$$

* Young's 'Nat. Phil.'

And for inclined beams, c being the angle of inclination,

$$\sqrt[4]{\frac{L^3 \times W \times a \times \cos. c}{23 \cdot 2 \times \Delta}} = D. \qquad [6]$$

91. The deflection of square beams is the same, whether strained in direction of the side or diagonal.

Tables of Experiments on the Stiffness of Wood.

92. Duhamel made some experiments on oak where the scantlings were as large as they are generally used in buildings; and as the results of experiments on large pieces will be more highly valued by the generality of readers, as many of them as are applicable to the present purpose will be described.

A piece of oak 9·6 inches deep and 10·66 inches in breadth, was placed upon two supports 24·5 feet apart, and a weight of 8198 lbs. was suspended to the middle, which bent it 3·73 inches. The piece broke with 9613 lbs., but it was found to have been faulty. Here the value of a for a deflection of $\frac{1}{40}$ of an inch per foot in length is 0·0114.

Another piece of oak, which was very sound and straight grained, the depth 12·2 inches, the breadth 10·66 inches, and the bearing 24·5 feet, with a weight of 8198 lbs. bent 2·65 inches. Whence for a deflection of $\frac{1}{40}$ of an inch per foot in length, $a = 0 \cdot 0157$. The piece broke with a weight equivalent to 19,666 lbs. applied to the middle.

A third piece of oak, that was sound and straight grained, was tried; the depth was 13·83 inches, the breadth 12·8 inches, and the length 24·5 feet; and with a weight of 8198 lbs. it bent an inch in the middle.* Therefore for a deflection of $\frac{1}{40}$ of an inch per foot $a = 0 \cdot 011$.

* 'Mémoires de l'Académie des Sciences,' Paris, 1768, pp. 535–537.

93. TABLE VI.—EXPERIMENTS on the STIFFNESS of OAK SUPPORTED at the ENDS.

Kind of Oak.	Spec. grav.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection in inches.	Weight producing the deflection in lbs.	Values of a.	Authorities.
Old ship timber	·872	2·5	1	1	0·5	127	·00998	Tredgold.
Oak from young tree, King's Langley, Herts	·863	2	1	1	0·5	237	·0105	,,
Oak from Beaulieu, Hants ..	·616	2·5	1	1	0·5	78	·0164	,,
Ditto, another specimen ..	·736	2·5	1	1	0·5	65	·0197	,,
Oak from old tree	·625	2	1	1	0·5	103	·024	,,
Oak from Riga .	·688	2	1	1	0·5	233	·0107	,,
English oak ..	·960	7	2	2	1·275	200	·0119	Barlow.
Canadian oak ..	·867	7	2	2	1·07	225	·009	,,
Dantzic oak ..	·787	7	2	2	1·26	200	·0105	,,
Adriatic oak ..	·948	7	2	2	1·55	150	·0193	,,
English oak ..	·748	2·5	1	1	0·5	137	·00934	Ebbels.
Ditto, green ..	·763	2·5	1	1	0·5	96	·0133	,,
Dantzic oak, seasoned	·755	2·5	1	1	0·5	148	·0087	Tredgold.
Oak, seasoned ..	..	12·8	3·19	3·19	1·06 4·25	268 803	·088 ·0105	Aubry.
Oak, green ..	..	6·87	5·3	5·3	·433	7587	·005	Buffon.
Oak, green ..	..	23·58	5·3	5·3	2·7	706	·0095	,,
Oak	..	8·52	5·06	6·22	0·709	4146	·0133	Girard.
Oak (bois du brin*)	..	16·86	10·66	11·73	0·67	4559	·0213	,,
Oak (quercus sessiliflora) ..	..	2	1	1	0·35	149	·0117	Tredgold.
Oak (quercus robur†)	..	2	1	1	0·35	167	·0104	,,

* "Bois du brin," timber the whole size of the tree, excepting that which was taken off to render it square.

† See Section on "Nature of Timber," where the characters of these species are described.

4. TABLE VII.—EXPERIMENTS on the STIFFNESS of FIR SUPPORTED at the ENDS.

Kind of Fir.	Spec. grav.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection in inches.	Weight producing the deflection in lbs.	Values of *a*.	Authorities.
Riga yellow fir, medium ..	..	18	2	7	0·25	103	·0115	Tredgold.
Yellow fir, from Long Sound, Norway .	·6398	2	1	1	0·5	261	·00957	,,
Yellow fir, Riga	·480	2·5	1	1	0·5	123	·0102	,,
	·464	2·5	1	1	0·5	116	·011	Ebbels.
Ditto, Memel, medium .	·553	2·5	1	1	0·5	143	·0089	Tredgold.
	·541	2·5	1	1	0·5	115	·0088	
American pine, supposed to be the Weymouth pine .	·460	2	1	1	0·5	237	·0105	,,
	·407	3	1	1	0·5	69	·0112	
White spruce, Christiana ..	·512	2	1	1	0·5	261	·00957	,,
White spruce, Quebec ..	·4650	2	1	1	0·5	180	·0138	,,
Pitch pine ..	·712	7	2	2	1·33	150	·0166	Barlow.
New England fir	·560	7	2	2	·970	150	·0121	,,
Riga fir	·765	7	2	2	·912	150	·01137	,,
Scotch fir, Mar Forest	·715	7	2	2	1·560	125	·0233	,,
Larch, Blair, Scotland, dry	·622	2·5	1	1	0·5	93	·0137	Tredgold.
Ditto, seasoned, medium ..	·644	2·5	1	1	0·5	101	·0126	,,
	·554	2·5	1	1	0·5	112	·0111	Ebbels.
Ditto, very young wood	·396	2·5	1	1	0·5	45	·0284	Tredgold.
Scotch fir * ..	·529	2·5	1	1	0·5	89	·01437	,,
Spruce fir, British	·555	2·5	1	1	0·5	103	·0124	Ebbels.
Fir (bois du brin)	..	21·3	10·48	10·4	1·02	4389	·0115	Girard.
Fir (bois du brin)	..	10·65	10·48	10·48	0·2245	4122	·022	,,

* The tree from which this specimen was taken was grown in Buckinghamshire.

95. TABLE VIII.—EXPERIMENTS on the STIFFNESS of VARIOUS WOODS SUPPORTED at the ENDS.

Kind of Wood.	Spec. grav.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection in inches.	Weight producing the deflection in lbs.	Values of *a*.	Authorities.
Ash from young tree, white coloured	·811	2·5	1	1	0·5	141	·009	Tredgold.
Ash from old tree, red coloured	·753	2·5	1	1	0·5	113	·0113	,,
Ash, medium quality ..	*·690*	*2·5*	*1*	*1*	*0·5*	*78·5*	*·0163*	*Ebbels.*
Ash	·760	7	2	2	1·27	225	·0105	Barlow.
Beech	·688	7	2	2	1·025	150	·01277	,,
Teak	·744	7	2	2	1·276	300	·0076	,,
Elm	·540	7	2	2	1·42	125	·0212	,,
	·544	2·5	1	1	0·5	99·5	·0128	Ebbels.
Cedar of Lebanon	·486	2·5	1	1	0·5	36	·0355	Tredgo
Maple, common	·625	2·5	1	1	0·5	65	·0197	,,
Abele	·511	2·5	1	1	0·5	84	·0152	,,
Willow	·405	2·5	1	1	0·5	41	·031	,,
Horse chestnut	·4838	2·5	1	1	0·5	79	·0162	,,
Lime-tree ..	·483	2·5	1	1	0·5	84	·0152	,,
Walnut, green	·920	2·5	1	1	0·5	62	·020	Ebbels.
Spanish chestnut, green ..	·895	2·5	1	1	0·5	68·5	·0187	,,
Acacia, green ..	·820	2·5	1	1	0·5	125	·0102	,,
Plane, dry ..	·648	2·5	1	1	0·5	99·5	·0128	,,
Alder, ditto ..	·555	2·5	1	1	0·5	80·5	·0159	,,
Birch, ditto ..	·720	2·5	1	1	0·5	90·5	·0141	,,
Beech, ditto ..	·690	2·5	1	1	0·5	97·5	·0131	,,
Wych elm, green	·763	2·5	1	1	0·5	92	·014	,,
Lombardy poplar, dry ..	·374	2·5	1	1	0·5	56·5	·0224	,,
Honduras mahogany ..	·560	2·5	1	1	0·5	118	·0109	Tredgold.
Spanish ditto ..	·853	2·5	1	1	0·5	93	·0137	,,
Sycamore ..	·590	2·5	1	1	0·5	76	·0168	Ebbels.
Pear-tree, green	·792	2·5	1	1	0·5	59·5	·0215	,,
Cherry - tree, green	·690	2·5	1	1	0·5	92·5	·0138	,,

96. The experiments in the following Tables were made by Mr. Fincham, to ascertain the relative qualities of timber used for the masts of ships. They were made with great care.*

97. TABLE IX.—PIECES SUPPORTED at BOTH ENDS and LOADED at the MIDDLE. (Green.)

Length = 4 feet between Supports. Scantling = 3 in. × 3 in.

Description of Timber.		Spec. grav.	Deflection with 1680 lbs.	What it recovered after removal of Weight	Deflection with 2520 lbs.	What it recovered after removal of Weight.	Deflection with 2520 lbs. left on for one hour	What it recovered after removal of Weight	Weight that broke the Piece.	Values of a.
			in.	in.	in.	in.	in.	in.	lbs.	
Riga fir	Top	·664	·31	·29	·62	·59	·97	·91	3654	·0093
,,	Butt	·720	·25	·22	·53	·50	·85	·73	3958	·0075
Red pine	Top	·627	·81	·68	1·37	1·13	1·40	1·10	2630†	·0241
,,	Butt	·712	·63	·59	·95	·91	1·20	1·05	3244†	·0190
American spruce	Top	·598	·37	·36	·62	·60	1·87	·95	2406†	·0111
	Butt	·643	·31	·29	·63	·61	1·07	·95	2646†	·0093
Norway fir	Top	·572	·57	·50	·82	·80	1·37	·93	2408†	·0172
	Butt	·595	·58	·56	·84	·82	1·37	·95	2618†	·0175
Adriatic	Top	·532	·30	·29	·42	·40	..	..	2386	·0090
,,	Butt	·582	·29	·27	·43	·41	·65	·45	2592	·0087
Yellow pine	Top	·553	·89	·77	1·48	1·10	..	..	2408	·0268
,,	Butt	·661	·73	·60	1·00	·90	..	..	2686	·0220
Scotch spruce	Top	·478	·84	·83	..	..	..	..	2072	·0253
	Butt	·542	·72	·70	..	..	..	..	2190	·0217
Kowrie	Top	·626	·31	·30	·43	·41	·62	·54	3983	·0093
,,	Butt	·643	·31	·30	·43	·41	·62	·54	4032	·0093

* Papers on Naval Architecture, vol. i., pp. 53–4.

† Broke off after the pressure had continued about 5 minutes.

98. Table X.—Pieces Supported at Both Ends and Loaded at the Middle. (Dry.)

Length = 4 feet between Supports. Scantling = 3 in. × 3 in.

Description of Timber.		Spec. grav.	Deflection with 1680 lbs.	What it recovered after removal of Weight.	Deflection with 2520 lbs.	What it recovered after removal of Weight.	Deflection after one hour's pressure with 2520 lbs.	What it recovered after removal of Weight.	Weight that broke the Piece.	Values of *a*.
			in.	in.	in.	in.	in.	in.	lbs.	
Riga fir	Top	·516	·50	·48	·93	·87	1·01	·97	3616	·0151
"	Butt	·633	·31	·30	·62	·56	·97	·85	3850	·0093
Red pine	Top	·514	·56	·51	1·25	1·13	1·37	1·20	2576	·0169
"	Butt	·644	·42	·50	·62	·56	·69	·60	2800	·0127
American spruce	Top	·488	·47	·38	·91	·87	1·08	·97	2546	·0142
	Butt	546	·47	·35	·82	·78	1·06	·94	2549	·0142
Norway fir	Top	·464	·51	·49	·83	·81	..	..	2366*	·0154
"	Butt	·506	·57	·56	·84	·80	1·00	·81	2590*	·0172
Adriatic	Top	·443	·27	·25	..	..	..	..	2378	·0081
"	Butt	·462	·25	·23	..	..	..	..	2515	·0075
Yellow pine	Top	·395	·60	·48	..	..	..	..	2380	·0181
"	Butt	·442	·66	·50	·99	·67	1·60	1·21	2632	·0199
Scotch spruce	Top	·348	·75	·72	..	..	..	..	1750	·0226
	Butt	·442	·62	·61	..	..	..	..	1848	·0187
Kowrie	Top	·560	·56	56	·68	·64	·75	·67	3612	·0169
"	Butt	·582	·27	·27	·43	·43	·50	·48	3948	·0081
Poona	Top	·632	·32	·32	·61	·60	·64	·62	3990	·0096
"	Butt	·658	·25	·25	·56	·56	·62	·61	4180	·0075

99. Table XI.—Pieces Supported at Both Ends and Loaded at the Middle. (Very dry and particularly good.)

Length = 4 feet between Supports. Scantling = 3 in. × 3 in.

Description of Timber.	Spec. grav.	Deflection with 1680 lbs.	What it recovered after removal of Weight.	Deflection with 2520 lbs.	What it recovered after removal of Weight	Deflection after one hour's pressure with 2520 lbs.	What it recovered after removal of Weight.	Weight that broke the Piece.	Values of *a*.
		in.	in.	in.	in.	in.	in.	lbs.	
Riga fir	·610	·25	·25	·37	·33	·40	·33	4530	·0075
Red pine	·544	·36	·35	·68	·62	·86	·78	3780	·0108
Yellow pine ..	·439	·37	·30	·78	·72	1·00	·82	2756	·0111
Norway fir ..	·517	·31	·30	·61	·60	86	·63	3292	·0093
Scotch pine ..	·453	·62	·60	·93	·90	..	..	2520	·0187
Kowrie	·579	·29	·29	·46	·44	·50	·15	4110†	·0087

* Very good specimens. † Broke after pressure had continued 15 minutes.

100. By means of equation [4] the following rules have been obtained. In that equation $40 \times \Delta$ equals L, and if L be substituted the equation becomes—

$$\frac{L \times B \times D^3}{L^3 \times W} = a; \qquad [7]$$

or in its simplest form,

$$\frac{B \times D^3}{L^2 \times W} = a. \qquad [8]$$

101. The constant number a is calculated on the supposition that the deflection is equal to $\frac{1}{40}$ of an inch for each foot in length: that is, when the length is 1 foot the weight will produce a deflection of $\frac{1}{40}$ of an inch; when the length is 20 feet, the deflection will be $\frac{20}{40}$, or half an inch, and so on. When the deflection is required to be less than here assumed, multiply the constant number a by some number that will reduce the deflection to the proposed degree; for instance, if the deflection should be only half of $\frac{1}{40}$, multiply a by 2; if one-third of $\frac{1}{40}$, multiply a by 3, &c. Also, if the deflection may be greater than $\frac{1}{40}$ per foot, divide a by 2, 3, or any number of times that the proposed deflection may exceed $\frac{1}{40}$ of an inch per foot.

Rules for the Stiffness of Beams.

102. To find the scantling of a piece of timber that will sustain a given weight when supported at the ends in a horizontal position.

Case I.—When the Breadth is Given.

Rule V.—*Multiply the square of the length in feet by the weight in pounds, and this product by the value of* a *opposite the kind of wood in the preceding Tables.* (Tables VI., VII., &c.) *Divide the product by the breadth in inches, and the cube root of the quotient will be the depth in inches.*

Example.—A beam of Norway fir is required for a 24 feet bearing to support 900 pounds, and the breadth to be 6 inches; what should be the depth? Here

$$\frac{24 \times 24 \times 900 \times \cdot 00957}{6} = 827;$$

and the cube root of 827 is 9·38, the depth required in inches.

Case 2.—When the Depth is Given.

103. Rule VI.—Multiply the square of the length in feet by the weight in pounds, and multiply this product by the value of *a* opposite the name of the kind of wood in Tables VI., VII., &c. Divide the last product by the cube of the depth in inches, and the quotient will be the required breadth in inches.

Example.—The space for a beam of oak does not allow it to be deeper than 12 inches; to find the breadth, so that it may support a weight of 4000 pounds, the bearing being 16 feet. Here $\frac{16 \times 16 \times 4000 \times \cdot 0164}{12 \times 12 \times 1} = 9\frac{3}{4}$ inches nearly, the breadth required.

104. But, generally, neither the breadth nor depth is given: in this case it will be best to fix on some proportion which the breadth should have to the depth; for instance, suppose it be convenient to make the breadth to the depth as 0·6 is to 1, then the rule would become as follows:

Rule VII.—Multiply the weight in pounds by the value of *a* opposite the kind of wood in the foregoing Tables (Tables VI., VII., &c.); divide the product by 0·6, and extract the square root. Multiply this root by the length in feet, and extract the square root a second time, which will be the depth in inches required. The breadth is equal to the depth multiplied by the decimal 0·6. It is obvious that any

other proportion of the breadth and depth may be obtained by merely changing the decimal 0·6 in the rule.

Example.—A beam of Riga fir is intended to bear a ton weight in the middle of its length, the bearing is 22 feet; what should be the dimensions of the beam? A ton is 2240 lbs. Here $\frac{2240 \times \cdot 011}{\cdot 6} = 41 \cdot 066$; the square root of 41·066 is 6·4 nearly. Therefore $6 \cdot 4 \times 22 = 140 \cdot 8$; and the square root of 140·8 is 11·86 inches, the depth required. And $11 \cdot 86 \times \cdot 6 = 7 \cdot 116 =$ the breadth.

105. When the beam is inclined the scantling will be found by the following rule:

Rule VIII.—Multiply together the weight in pounds, the cosine of the angle the beam makes with the horizon to a radius of unity, and the constant number *a* for the kind of wood; divide this product by 0·6, and extract the square root of the quotient. Multiply this root by the length in feet, and extract the square root again, which will give the depth in inches.

106. Otherwise, let AB (Fig. 25, page 27) be the beam, and B C a vertical line; then A C will be the horizontal distance between the points of support.

Rule IX.—Multiply together the weight in pounds, the length of the beam in feet, the horizontal distance between the supports in feet, and the constant number *a* for the kind of wood; divide this product by 0·6, and the fourth root of the quotient will give the depth in inches. According to either rule, the breadth is assumed to be equal to the depth multiplied by the decimal 0·6.

Example.—Let the length of the beam be 20 feet, and the horizontal distance between the points of support 16 feet, and the weight to be supported one ton, or 2240 pounds, by a beam of Riga fir. Then $\frac{2240 \times 20 \times 16 \times \cdot 011}{\cdot 6} = 13240$;

the fourth root of 13240 is $10\frac{3}{4}$ nearly, and $10\frac{3}{4} \times \cdot 6 = 6\frac{1}{2}$ nearly; therefore the beam should be $10\frac{3}{4}$ inches by $6\frac{1}{2}$ inches.

When a Beam is Fixed at Both Ends and Loaded in the Middle.

107. The strain upon a beam fixed at both ends has excited much attention, in consequence of a supposed difference between the results of theory and experiment. If it had been possible to fix a beam so that it should not have suffered extension beyond the point of fixing, the demonstrations of Emerson* and Professor Robinson† would have been perfectly correct; but it is evident that the beam will be extended beyond the point of support, and the quantity of extension must depend on the mode of fixing. According to the experiments of Belidor, the strength of a beam fixed at both ends is to the strength of a beam only supported at the ends as 3 is to 2.‡ M. Parent obtained nearly the same result. The stiffness will be nearly in the same proportion.

But we cannot in practice fix the ends of a beam into a wall without endangering its stability, therefore the determination of the stiffness of beams to suit such a case is not of much importance.

When, however, a long beam AB, is laid over several points of support, as in Fig. 42, a case of very common

Fig. 42.

occurrence in building, the strength of the intermediate parts is nearly doubled, or twice as much as when the beams

* Emerson's 'Algebra,' prob. 182, p. 464.

† 'Encyclopaedia Britannica,' art. Carpentry.

‡ 'Sciences des Ingenieurs,' liv. iv., chap. 3.

are cut into short lengths. Hence the carpenter will see the importance of using bridging and ceiling joists, and purlins, and rafters, in considerable lengths, so that a joist may extend over several binding joists, purlins over several trusses, and a rafter over several purlins; also, by contriving the joinings so that they shall not be opposite one another, a floor or roof may be made tolerably equal in strength. Hence, also, we see the importance of notching joists, purlins, and rafters over the supports, instead of framing them between.

Of the Stiffness of Cylinders Supported at Both Ends.

108. When a solid cylinder is supported at both ends. Let D be the diameter of the cylinder; then

$$W \times L^2 \times \text{constant quantity} = D^4. \qquad [9]$$

Now it is shown by Dr. Young that the stiffness of a cylinder is to that of its circumscribing rectangular prism, as three times the bulk of the cylinder is to four times the bulk of the prism;* and as the stiffness of the prism is $= \dfrac{D^4}{a \times L^2}$;

therefore $\dfrac{3 \times \cdot 7854 \times D^4}{4\,a \times L^2} = W$, or $1{\cdot}7\,a \times L^2 \times W = D^4$. [10]

From want of proper experiments this method of obtaining the stiffness of cylinders has been resorted to - as the only experiments on cylinders, where the first deflections are given, are those of Duhamel, which were made on very small specimens.†

109. To find the diameter of a solid cylinder, so that it may be capable of supporting a given weight, without deflecting more than $\frac{1}{40}$ of an inch for each foot in length.

Rule X.—Multiply the value of a for the kind of wood from the Tables (Arts. 93, 94, &c.), by 1·7, and multiply this product by the weight in pounds. Then multiply the square

* 'Natural Philosophy.' † 'Transport du Bois,' p. 460.

root of the last product by the length in feet, and the square root of the quotient will be the diameter of the cylinder in inches.

Example.—A solid cylinder of elm is intended to support 10 hundredweight (or 1120 pounds), the length of bearing 10 feet; required the diameter? The constant number for elm being ·0212, by one of the experiments in Table VIII., Art. 95.

In this case we have $1·7 \times ·0212 \times 1120 = 40·3648$, the square root of which is 6·35, therefore $10 \times 6·35 = 63·5$; and the square root 7·97, or nearly 8 inches, which is the diameter required.

THE STIFFNESS OF BEAMS SUPPORTED AT BOTH ENDS, AND THE WEIGHT UNIFORMLY DISTRIBUTED OVER THE LENGTH.

110. Where the load is uniformly distributed over the length of the beam, the deflection does not increase in the same proportion as when it acts at one point. For where the weight is uniformly diffused it increases as the length, and the deflection will be as the fourth power of the length; consequently, according to the definition given in Art. 85, the stiffness will be as the cube of the length.

The stiffness of a beam uniformly loaded may be derived from the general proportion $B\,D^3$ is as $L^3\,W$.

This proportion applies to the case of the rafters, and purlins of a roof, to ceiling joists, and binding joists that support ceilings only, but it does not apply to flooring joists, because their stiffness is measured by the resistance offered to a strain at one point; a floor might seem stiff enough to support a uniform load, and yet shake very much by the weight of a single person moving over it.

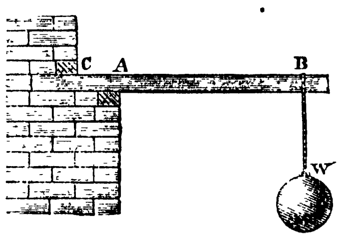
111. The above method may be applied in cases where beams are similarly loaded, as in rafters, ceiling joists, &c., but another manner of determining the stiffness may be used in other cases.

For let W be the weight that is uniformly distributed over a beam supported at both ends, then the deflection produced by this weight would be to the deflection produced by the same weight collected in the middle of the length as 5 : 8, or as 0·625 : 1.* Therefore, in the rules in Arts. 102, 103, 104, and 105, it is only necessary to employ the weight in pounds multiplied by 0·625 instead of the whole weight, and the rest of the operation is the same as in those rules; therefore it will not be necessary to repeat them.

Of the Stiffness of Beams Supported at One End.

112. When a beam is fixed at one end and loaded at the other the deflection is sixteen times greater than when merely supported at both ends and loaded at the middle; but the deflection is much modified by fixing the beam as in Fig. 43; it increases with the distance A C, because the parts between A and C will be extended, and of course increase the deflection. And as it is impossible to fix a bar so that it will not be extended beyond the point of support, there is much irregularity in the results of experiments on beams fixed in this manner.

Fig. 43.



The forms of the equations [2], [3], [4], &c., remain the same, only a different constant quantity b must be used, which, if the beam be perfectly fixed at one end, is sixteen times greater than the constant a. It is, however, obtained directly from the following Table of Experiments.

* The demonstration is given in the 'Encyclopædia Britannica,' art. Carpentry, and in Barlow's 'Essay on the Strength of Timber,' and also is evident from arts. 326 and 330 of Dr. Young's 'Natural Philosophy,' Vol. ii.

113. TABLE XII.—EXPERIMENTS on the STIFFNESS of BEAMS FIXED at ONE END.

Kind of Wood.	Spec. grav.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection in inches.	Weight producing the deflection in lbs.	Values of constant quantity *b*.	Authorities.
Dantzic oak ..	·854	4	2	2	2·5	112	·223	Beaufoy.
English oak ..	·922	4	2	2	1·176	112	·105	,,
Ditto, another specimen ..	..	4	2	2	1·5	112	·1335	,,
Riga fir	·537	4	2	2	1·34	112	·12	,,
Pitch pine ..	..	4	2	2	1·12	112	·099	,,*
Beech	..	3	2	2	3·375	221	·313	Barlow.

114. TABLE XIII.—EXPERIMENTS on BEAMS FIXED at ONE END. (FINCHAM.)

Length = 2 feet beyond Support. Scantling = 3 in. × 3 in.

Description of Timber.		Specific gravity.	Deflection. With 560 lbs.	With 1120 lbs.	With 1400 lbs.	With 1680 lbs.	Weight that broke the piece.	Values of *b*.	Remarks.
			in	ins.	ins	ins.	lbs.		
Riga fir	Top	·605	·52	1·02	2·07	3·10	1818	·3761	All the specimens were dry.
,,	Butt	·668	·40	·80	1·50	2·87	2100	·2893	
,,	,,	·821	·37	1·00	1·37	1·62	1820	·2676	
Red pine	Top	·514	·63	1·42	2·68	..	1630	·4556	
,,	Butt	·634	·60	1·07	1·95	..	1877	·4339	
American spruce	Top	·504	·56	1·32	2·13	..	1518	·4050	
	Butt	·570	·50	·90	1·67	..	1786	·3616	
Norway fir	Top	·464	·55	1·04	..	..	1370	·3978	
,,	Butt	·506	·62	1·35	1·97	3·00	1860	·4484	
Adriatic	Top	·467	·50	1·00	2·00	..	1454	·3616	
,,	Butt	·493	·40	·70	1·40	..	1716	·2893	
Yellow pine	Top	·406	·62	2·00	..	..	1260	·4484	
,,	Butt	·493	·63	2·12	..	..	1390	·4556	
Scotch spruce	Top	·389	·58	..	..	..	1108	·4195	
	Butt	·440	·54	2·00	..	..	1230	·3906	
Kowrie	Top	·626	·37	·75	1·12	1·62	1960	·2676	
,,	Butt	·632	·50	·87	1·25	1·87	2100	·3616	
Poona Top,	Outside	·654	·46	·62	·90	1·40	2086	·3327	
,,	Heart	·608	·62	..	..	..	1110	·4484	
Poona Butt,	Outside	·666	·37	·75	1·00	1·25	2338	·2676	
,,	Heart	·646	·57	·80	..	..	1228	·4122	

In Colonel Beaufoy's experiments the mean result has been taken of the most regular of his experiments, and the deflection converted into inches. His experiments are published in Thomson's 'Annals of Philosophy,' vol. ix., p. 274.

115. As beams fixed at one end are not frequently used in the construction of buildings, it will be unnecessary to repeat the rules in words at length.

When the beam is fixed in a horizontal position,

$$\left(L \times \left(\frac{b \times W}{0 \cdot 6}\right)^{\frac{1}{2}}\right)^{\frac{1}{2}} = D. \qquad [11]$$

And $0 \cdot 6\ D = B$.

When the beam is inclined, and c is the angle of inclination,

$$\left(L \times \left(\frac{b \times \cos.c \times W}{0 \cdot 6}\right)^{\frac{1}{2}}\right)^{\frac{1}{2}} = D. \qquad [12]$$

And $0 \cdot 6\ D = B$.

When a solid cylinder is fixed at one end,

$$\left(L \times (1 \cdot 7b \times W)^{\frac{1}{2}}\right)^{\frac{1}{2}} = D. \qquad [13]$$

Where the value of b may be obtained from the preceding Table, and the deflection is calculated to be $\frac{1}{40}$ of an inch per foot in length.

When the Weight is uniformly distributed over the Length of Beams Fixed at One End.

116. When the weight W is uniformly diffused over the length of the beam, the deflection is to the deflection of a beam loaded in the middle as $\cdot 75 : 2$; or as $\cdot 375 : 1$. Therefore, instead of W in the above equation substitute $\cdot 375$ W, and the scantlings for beams uniformly loaded may be obtained.

ON THE STRENGTH OF BEAMS TO RESIST CROSS STRAINS.

117. The strength of a beam, or the weight that it would carry without fracture, is determined by the relation which exists between the moment of rupture and the moment of resistance to rupture, termed the equality of moments as explained in Art. 44.

118. The moment of resistance is the sum of the forces due to the resistance of the fibres of the beam at the place of rupture, to tearing and crushing, multiplied by their respective distances from the neutral axis of the cross section.*

119. As the position of the neutral axis varies for each description of wood owing to the different degrees of resistance to tension and compression, it will be sufficient for the carpenter's purpose to know, as shown by writers on the Strength of Materials, that in solid beams of rectangular cross section, the moment of resistance is proportional to the area of the section at the point of rupture, multiplied by the depth of the beam and by a constant number, which has to be found by experiment for each description of wood.† Therefore, if κ be taken to represent the constant, B to represent the breadth of the beam, D its depth, and L its length between the supports—all in the same terms—and W the weight as before, we have

$$\text{Moment of resistance } M^R = B \times D \times D \times \kappa = B \times D^2 \times \kappa.$$

This being taken equal to the moment of rupture M (Sect. 1) we have for the strength of a beam supported at both ends (Art. 47)

$$B \times D^2 \times \kappa = \frac{W \times L}{4}; \text{ or } \frac{4 \times \kappa \times B, \times D^2}{L} = W, \quad [14]$$

* This is usually represented by the moment of inertia of the section multiplied by the intensity of stress on the extreme fibres per unit of area divided by the distance from the neutral axis.

† Tate 'On the Strength of Materials.'

a formula which gives the weight that would fracture a beam when loaded in the middle.

In practice it is more convenient to take the length of the beam in feet, the other dimensions being in inches, which requires the formula to be modified thus :—

$$\frac{B \times D^2}{L} \times \frac{\kappa}{3} = W. \qquad [15]$$

The constant κ must be ascertained by experiment, and as the divisor 3 in the formula will also be constant, the formula may be still further simplified by taking $c = \frac{\kappa}{3}$ as

$$\frac{B \times D^2}{L} \times c = W; \qquad [16]$$

where c is the constant number in the Table, and can be determined by the equation

$$\frac{L \times W}{B \times D^2} = c. \qquad [17]$$

120. In this manner the strength of any beam with a rectangular cross section may be obtained, no matter how the load may be placed upon it.

121. When a square beam is strained in the direction of its diagonal the strength is decreased in the proportion of 0·7071 to 1.*

122. The strength of a solid cylinder is as the cube of its diameter (= D),† therefore $\frac{D^3 \times c}{L \times 1{\cdot}7} = W.$ [18]

The ratio of the strength of square beams to cylinders being the same as their stiffness.

A hollow cylinder is both stronger and stiffer than a solid one containing the same quantity of material; therefore,

* 'Philosophical Magazine,' vol. l., p. 418, and Stoney's 'Theory of Strains,' p 51.

† Emerson's 'Mechanics,' sect. viii.; Gregory's 'Mechanics,' vol. i.

where it is desirable to combine strength and lightness, cylinders may be made hollow. In timber this is rather too expensive an operation to be often employed; but there are cases where it is useful. The strength of a tube, or hollow cylinder, is to the strength of a solid one as the difference between the fourth powers of the exterior and interior diameters of the tube divided by the exterior diameter, is to the cube of the diameter of a solid cylinder: the quantity of material in each being the same.

123. A beam with a triangular cross section, supported at the ends, is about *one-tenth* stronger when the base is upwards than when it is downwards, but in the former case the sharp angle has to be cut partly away to give a bearing on the supports.

124. The strongest beam that can be cut out of a round tree is that of which the depth is to the breadth as the square root of 2 is to 1;* or nearly as 7 is to 5. And the strength of a square beam cut from the same cylinder, or round tree, is to the strongest beam nearly as 101 is to 110; but the square beam would contain more timber nearly in the ratio of 5 to 4·714.

Experiments on the Strength of Beams supported at Both Ends.

125. On this kind of strength the experiments are most numerous, and some of the most important are collected in the following Table:—

* This was first demonstrated by M. Parent in the 'Mémoires de l'Académie,' Paris, for 1708.

TABLE XIV.—EXPERIMENTS on the STRENGTH of WOODS.

Kind of Wood.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection at the time of fracture in inches.	Weight that broke the piece in lbs.	Values of the constant c.	Authorities.
Oak, English, young tree	·863	2	1	1	1·87	482	964	Tredgold.
Oak, English, old ship timber	·872	2·5	1	1	1·5	264	660	,,
Oak, English, from old tree	·625	2	1	1	1·38	218	436	,,
Oak, English, medium quality	·748	2·5	1	1	..	284	710	Ebbels.
Oak, English, green	·763	2·5	1	1	..	219	547	Tredgold.
Oak, from Riga ..	·688	2	1	1	1·25	357	714	,,
,, green	1·063	11·75	8·5	8·5	3·2	25812	595	Buffon.
,, Canada, mean of four experiments ..	·802	4·0	3	3	..	3863	572	Fincham.
Oak, Dantzic	·704	4	3	3	..	4450	622	,,
Beech, medium quality	·690	2·5	1	1	..	271	677	Ebbels.
Alder	·555	2·5	1	1	..	212	530	,,
Plane-tree	·648	2·5	1	1	..	243	607	,,
Sycamore	·590	2·5	1	1	..	214	535	,,
Chestnut, green ..	·875	2·5	1	1	..	180	450	,,
Ash, from young tree	·811	2·5	1	1	2·5	324	810	Tredgold.
,, medium quality	·690	2·5	1	1	..	254	635	Ebbels.
,, ...	·753	2·5	1	1	2·38	314	785	Tredgold.
Elm, common	·544	2·5	1	1	..	216	540	Ebbels.
,, wych, green ..	·763	2·5	1	1	..	192	480	,,
Acacia, green	·820	2·5	1	1	..	249	622	,,
Mahogany, Spanish, seasoned	·852	2·5	1	1	..	170	425	Tredgold.
Mahogany, Honduras, seasoned	·560	2·5	1	1	..	255	637	,,
Mahogany, New South Wales	1·382	4	3	3	..	119	610	Fincham.
Walnut, green	·920	2·5	1	1	..	195	487	Ebbels.
Poplar, Lombardy ..	·374	2·5	1	1	..	131	327	,,
,, abele	·511	2·5	1	1	1·5	228	570	Tredgold.
Teak	·744	7	2	2	4·00	820	717	Barlow
,, Malabar	·724	4	3	3	..	4897	722	Fincham.
,, Moulmein ..	·909	4	3	3	..	3841	569	,,
,, Jahore	1·120	3	$1\frac{1}{2}$	$1\frac{1}{2}$	..	1213	1438	Mayne.
Willow	·405	2·5	1	1	3	146	365	Tredgold.
Birch	·720	2·5	1	1	..	207	517	Ebbels.
Cedar of Libanus, dry	·486	2·5	1	1	2·75	165	412	Tredgold
,, Bermuda ..	·932	4	3	3	..	4119	610	Fincham.
,, Cuba	·524	4	3	3	..	2727	404	,,

TABLE XIV.—*continued.*

Kind of Wood.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection at the time of fracture.	Weight that broke the piece in lbs.	Values of the constant c.	Authorities.
Cedar, N. S. Wales ..	·555	4	3	3	..	3179	471	Fincham.
,, Jahore	·648	3	$1\frac{1}{2}$	$1\frac{1}{2}$	..	616	547	Mayne.
Riga fir	·480	2·5	1	1	1·3	212	530	Tredgold.
Dantzic fir	·708	4	3	3	..	4124	611	Fincham.
Memel fir	·553	2·5	1	1	1·15	218	515	Tredgold
Norway fir, from Longsound	·639	2	1	1	1·125	396	792	,,
Mar Forest fir	·715	7	2	2	5·5	360	315	Barlow.
Scotch fir, English growth	·529	2·5	1	1	1·75	233	582	Tredgold.
,, ,,	·460	2·5	1	1	..	157	392	Ebbels.
Christiana white deal	·512	2	1	1	·937	343	686	Tredgold.
American white spruce	·465	2	1	1	1·312	285	570	,,
Spruce fir, British growth	·555	2·5	1	1	..	186	465	Ebbels.
American pine, Weymouth	·460	2	1	1	1·125	329	658	Tredgold.
Red pine, N. America	·512	4	3	3	..	3259	483	Fincham.
Yellow pine ,,	·437	4	3	3	..	2845	414	,,
Pitch pine ,,	·682	4	3	3	..	3339	495	,,
Larch, choice specimen	·640	2·5	1	1	3	253	632	Tredgold.
,, medium quality	·622	2·5	1	1	..	223	557	,,
,, very young wood	·396	2·5	1	1	1·75	129	322	,,
,, Hackmetack ..	·708	4	3	3	..	4243	628	Fincham.
Kowrie	·614	4	3	3	..	3732	553	,,
Saul	·880	..	..	..	..	..	881	Skinner.
Water gum, N.S. Wales	1·001	1	$1\frac{3}{4}$	$1\frac{3}{4}$	·43	4408	823	Fowke.
Blue gum ,,	·843	1	$1\frac{3}{4}$	$1\frac{3}{4}$	·19	4482	838	,,
Stringy bark ,,	·864	1	$1\frac{7}{8}$	$1\frac{7}{8}$	..	3078	467	,,
Bastard box ,,	1·115	1	$1\frac{1}{2}$	$1\frac{1}{2}$	·23	5892	1746	,,
Mora, British Guiana	·922	1	2	2	·19	9697	1212	,,
Greenheart, yellow, Guiana	1·052	·79	2	2	..	14528	1434	,,
Cedar, white, Berbice	·771	1	2	2	·37	7163	895	,,
Locust, British Guiana	·707	1	2	2	..	6171	771	,,
Boxwood, Jamaica ..	·690	1	2	2	..	5511	689	,,
Lancewood ,,	·675	1	2	2	..	7714	964	,,
Cedar ,,	·576	1	2	2	..	3196	399	,,
Lignum vitæ ,,	1·170	1	2	2	..	5069	633	,,
Bullet-tree ,,	1·016	1	2	2	·30	9920	1240	,,
West Indian ebony, Jamaica	1·193	1	$1\frac{3}{4}$	$1\frac{3}{4}$	..	8185	1583	,,

126. In these Tables, as in all the others, the author has endeavoured to collect experiments of such various kinds as would best show the strength of wood under different circumstances. He considers this preferable to taking mean results; and it will convey much more useful information to the reader. It will be seen that the specimens from aged trees are inferior in strength to those of mean age; and that the strength of green timber differs materially from that of seasoned or dry. Also, that the strength is greater in those specimens which are the most heavy; but the increase of strength is not exactly proportional to the increase of specific gravity.

Rules for the Strength of Beams supported at Both Ends.

127. To find the weight that would break a rectangular beam when applied at the middle of its length, the beam being supported at the ends.

Rule XI. Multiply the breadth in inches by the square of the depth in inches, divide this product by the length in feet, and the quotient multiplied by the value of c in Table XIV. corresponding to the kind of wood; the product will be the weight in pounds.

Example.—The length of a girder of Riga fir between the supports is 21 feet, its depth is 14 inches, and breadth 12 inches; to find the weight that would break it when applied in the middle. Opposite Riga fir in the Table we find $c = 530$; and $\frac{12 \times 14 \times 14 \times 530}{21} = 59{,}360$ pounds, or above 26 tons.

If a beam of the same scantling and length had been supported at one end only, one-fourth of the weight would have broken it.

128. To find the weight that would break a solid cylinder when applied at the middle of its length, the cylinder being supported at the ends.

RULE XII.—Find the value of c for the kind of wood in Table XIV., and divide it by $1 \cdot 7$; multiply the quotient by the cube of the diameter in inches, and divide the product by the length in feet; the quotient will be the weight in pounds that would break the cylinder.

Example.—What weight would break a solid cylinder of ash, 12 feet long and 8 inches diameter? For ash the value of c is 635 in the Table, therefore

$$\frac{635 \times 8 \times 8 \times 8}{1 \cdot 7 \times 12} = 15{,}937 \text{ pounds}$$

129. If the weight be uniformly diffused over the length of a beam, it will require to break it twice the weight that would break it when applied at the middle of its length.

130. If a beam be fixed at both ends and loaded in the middle, it has to break in three places instead of one; it will in that case carry $1\frac{1}{2}$ times more weight than if merely supported at both ends.

STRENGTH OF BEAMS FIXED AT ONE END.

131. The rules for beams fixed at one end and loaded at the other are precisely the same as those for beams supported at both ends, except that a different constant number must be used; *viz.* the constant d in the following Table, or the *constant number c for beams supported at both ends must be divided by 4.* If the weight be uniformly diffused over the length, the beam will bear double the weight that would break it when applied in the middle.

132. TABLE XV.—EXPERIMENTS on the STRENGTH of BEAMS SUPPORTED at ONE END.

Kind of Wood.	Specific gravity.	Length in feet.	Breadth in inches.	Depth in inches.	Deflection at the time of fracture in inches.	Weight that broke the piece in lbs.	Values of constant d.	Experimentalist.
English oak ..	·922	4	2	2	..	266	133	Beaufoy.
,, ..	..	4	2	2	..	210	105	,,
Dantzic oak ..	·854	4	2	2	..	196	98	,,
Beech	·700	3	2	2	11	401	150	Barlow.
,, ...	·740	2	1	2	5	352	176	,,
Ash	·658	3	2	2	11½	436	163	,,
,, ...	·730	2	1	2	6	321	160	,,
,, green ..	·858	5	2	2	16	239	149	Peake and Barrallier.
Teak, old, dry ..	·606	5	2	2	12½	257	161	,,
Dantzic fir, wet	·648	5	2	2	12½	157	97	,,
Riga fir	·537	4	2	2	..	210	105	Beaufoy.
,, dry ..	·633	5	2	2	14	153	93	Peake and Barrallier.
,, dry ..	·636	2	3	3	..	1974	146	Fincham.
Red pine	·589	2	3	3	..	1753	129	,,
Virginian yellow pine	·522	5	2	2	11¾	147	92	Peake and Barrallier.
Canadian white pine	·618	5	2	2	18¾	122	76	,,
Pitch pine	..	4	2	2	..	270	135	Beaufoy.
Larch, dry ..	·526	5	2	2	16¼	162	101	Peake and Barrallier.
American spruce	·537	2	3	3	2	1652	122	Fincham.
Kowrie (N. Zealand)	·629	2	3	3	..	2044	151	,,
Saul (India) ..	·880	..	..	..	..	..	220	Skinner.

Resistance to Detrusion.

133. Another kind of strain to which beams are liable, and which requires particular attention, as the strength of a piece of framing often depends upon it, is that tending to separate or shear the beam in the direction of its fibres.

According to the experiments of Professor Robinson, this resistance appeared to be exactly proportional to the area of the section, and quite independent of its figure.* Barlow made some experiments on this kind of resistance, from which it appears that when the force is parallel to the fibres, the strength of fir to resist detrusion is from 556 lbs. to 634 lbs. per square inch, or about one-twentieth of the cohesive force, in the direction of the fibres.†

Mr. Hatfield gives the amount of the force required to separate the fibres of the following kinds of timber grown in America, when applied *in the direction of the length*:‡—

	lbs. per sq. in.		lbs. per sq. in.
Spruce	470	Oak	780
Chestnut	690	Hemlock	540
White Pine	490	Georgia Pine ..	510
Ohio Pine	388	Locust	1180

134. To give an example of the application, let A C (Fig. 16) be the lower end of a principal rafter, and C B the tie-beam.

It is evident that if the part D be not sufficiently long, the thrust of the foot of the rafter will cause it to shear off at the line b C. If we suppose the joint to have no tenon, then the horizontal thrust of the rafter in pounds should be equal to the area of the surface in inches that would be forced asunder in case of fracture, multiplied by the resistance of a square inch in pounds.

* 'Ency. Britannica,' art. Strength of Materials.

† Essay on Strength of Timber. ‡ American House Carpenter.

In practice, the strain should not exceed one-fourth of the resistance; therefore, to find the length b C we have the following rule:—

Rule XIII.—Divide four times the horizontal thrust in pounds by the breadth in inches, multiplied into the shearing force of a square inch in pounds, in the direction of the fibres, and the quotient will give the length b C in inches.

Example.—Find the horizontal thrust of a rafter by the principles in Section I. (Art. 40). Let us assume this pressure to be 5600 pounds, and let the breadth of the tie-beam, which is of Georgia pine, be 6 inches, and the resistance to shearing 510 lbs. per square inch. Then

$$\frac{4 \times 5600}{6 \times 510} = 7 \cdot 3 \text{ inches nearly,}$$

for the distance b to C.

If the beam had been American oak, the resistance of a square inch of which is 780 lbs., there would be required $\frac{4 \times 5600}{6 \times 780} = 4 \cdot 8$ inches nearly.

A knowledge of this kind of resistance is useful in ascertaining the length a tenon should be from the pin-hole to prevent the former from tearing out. It was found by Mr. Bevan that a force of 976 lbs. was required to pull out a piece of Scotch fir applied as a tenon in a mortice, and fastened with a half-inch iron pin; the thickness of the tenon being ·87 inch, and the length from the centre of the pin-hole to the end 1·05 inch, the lateral cohesion of the wood being the same as in Table V., Art. 83.*

This rule is also useful in regulating the length of the scarfs in tie-beams, and other timbers subject to a tensile strain.

* 'Phil. Mag.,' vol. lxviii., 1826.

Resistance to Shearing across the Grain.

135. It would appear from experiments by Mr. Parsons, of Her Majesty's *dockyard service, on treenails used in ship-building*, that the force required to shear English oak across the grain was 4000 lbs. per square inch, or about *one-fourth* of the cohesive force in the direction of the fibres

OF THE RESISTANCE TO COMPRESSION.

136. When a pillar or other piece of timber is compressed in the direction of its length, the manner of yielding differs according to the proportion which the length bears to the least thickness or diameter. If the length be considerable as compared with the diameter, the pillar will bend, and ultimately fail by breaking at the middle, in the same manner as it would under a cross strain. A portion of the section at fracture will be found to have been compressed and another portion extended.

When the pillar is very short in proportion to the diameter, it cannot be bent by any force, however great, but will fail by crushing alone.

No satisfactory theory has ever been adduced which will embrace these extremes. Euler, Lagrange,* Poisson,† and others, who have treated the subject, have for the most part confined their attention to cases where the length greatly exceeded the diameter, and they assumed the law in these cases to follow that relating to transverse strains. Hodgkinson has shown that Euler's formula is true only on the supposition that failure takes place by bending, and not by the crushing of the material. It will be found, however, sufficiently near for practice when the length exceeds about

* 'Acad. de Berlin,' 1769; 'Collection Acad. de Turin,' vol. v.

† Poisson, 'Mécanique,' 2nd edit.

30 diameters, as in that case the load which would cause the pillar to bend is a small proportion of that which would crush a short column of the same sectional area.

In pillars of medium length, or those shorter than 30 diameters, the load required to produce flexure is so considerable a portion of the crushing weight that the elasticity of the material is destroyed. In this case Euler's formula, to be at all applicable, would require considerable modifications, and it would altogether fail in the case of very short pillars, or those where the length is less than about 5 diameters, which yield wholly by crushing.

Euler's theory assumes the resistance to flexure to be directly as the fourth power of the diameter, and inversely as the square of the length. It is to be remarked that so high a power as 4 for the diameter or 2 for the length has not been obtained in any of the experiments which have been made on the resistance of wood to compression. In those of Lamandé on pillars of oak, the power of the diameter deduced from pillars of 6 and 12 diameters in length is 2·186, and for pillars of 24 and 36 diameters in length it is 3·351. The powers of the length for the same pillars are ·108 and 1·177. And Hodgkinson's experiments on Dantzic oak of 17 and 35 diameters in length, show the power of the length to be very much less than the square.

137. The following Tables give the results of experiments made by various authorities on the resistance of wood to compression. But it is to be observed that in addition to the causes of variation in the resistance of timber referred to in Art. 75, a great difference is caused in the results according to the part of the tree from which the specimen is cut. The heart being stronger than the sapwood, and the butt stronger than the top, as shown by Fincham's experiments (Tables IX., X., and XIII.).

138. TABLE XVI.—EXPERIMENTS on the RESISTANCE of FRENCH OAK (seasoned), when PRESSED in the DIRECTION of its LENGTH.

(Lamandé.*)

Length in feet.	Breadth in inches.	Thickness in inches.	Deflection in inches.	Weight producing the deflection in lbs.	Duration of the experiments in hours.	Weight that broke the piece in lbs.
2·125	2·126	2·126	·0787	7,856	4	15,631
			·03937	13,525	6	21,296
			·1181	14,119	18	19,993
			·03937	11,750	8	21,060
4·25	2·126	2·126	·0787	6,298	21	11,844
			·1574	6,298	27	12,225
			·1574	6,298	..	13,565
			·1574	6,298	6	12,458
6·375	2·126	2·126	·1574	3,277	6	7,244
			·1574	2,860	..	7,484
			·2361	2,750	5	8,492
			·1574	2,750	..	7,878
2·125	3·18	3·18	·0787	34,599	27	50,958
			·03937	45,168	24	50,958
4·25	3·18	3·18	·1574	20,317	29	43,639
			·1574	18,647	5	36,865
			·19685	20,578	9	36,205
			·27559	21,819	17	28,182
6·375	3·18	3·18	·1574	9,121	7	26,939
			·19685	9,713	19	28,987
			·0787	11,000	4	23,929
			·2361	10,142	18	33,048
			·1574	12,746	6	36,902
2·125	4·25	4·25	·0787	61,883	11	95,262
			·03937	56,691	8	66,112
			·03937	56,693	23	105,826
			·0787	67,467	28	94,476
			·03937	57,780	30	88,442
4·25	4·25	4·25	·03937	63,066	8	100,755
			·0787	29,695	5	85,998
			·0787	50,525	19	73,238
			·03937	45,201	19	96,368
6·375	4·25	4·25	·1574	21,586	7	64,090
			·2361	17,331	5	59,373
			·1574	18,517	22	54,062
			·2361	27,599	22	65,608

* Gauthey's 'Construction des Ponts,' tom. ii., p. 48.

139. TABLE XVII.—EXPERIMENTS on the RESISTANCE of OAK when PRESSED in the DIRECTION of its LENGTH.

(Girard.*)

	Specific gravity.	Length in feet.	Breadth in inches.	Thick-ness in inches.	Deflection in inches.	Weight producing the deflection in lbs.	Duration of the experiments in hours.	Weight that broke the piece in pounds, or Remarks.
1	1·038	8·52	6·22	5·06	0·268	38,105	0·83	Recovered its first form.
3	1·010	8·52	6·22	4·00	0·09	26,381	0·83	Retained a slight flexure.
4	1·000	8·52	5·24	3·9	0·445	26,381	6·66	Idem.
5	·923	8·52	5·15	4·17	0·665	26,392	6·66	50,448
7	·973	7·46	6·22	5·06	Not sensible	38,098	0·83	
..	..	..	..	..	0·157	50,451	2·08	Recovered its first form.
8	·972	7·46	6·13	4·09	0·244	38,104	12·08	72,865
9	·925	7·46	6·22	4·00	0·267	38,106	12·08	62,977
10	1·038	7·46	4·97	4·00	0·312	26,397	10·00	Retained a slight flexure.
11	1·102	6·39	6·13	5·24	0·177	38,107	7·08	Idem.
13	·987	6·39	6·22	4·00	0·177	38,106	2·08	Recovered its first form.
15	1·032	6·39	5·24	4·17	0·22	38,048	10·00	Idem.
17	·920	7·46	6·22	4·25	0·114	26,396	10·00	Idem.
19	1·038	8·52	6·22	5·06	0·177	26,392	10·00	
20	·944	8·52	7·37	6·22	0·09	26,394	10·00	Recovered its first form.
21	·842	8·52	7·46	6·22	0·09	26,396	10·00	

The numbers in the first column correspond with those of the experiments selected from M. Girard's work. The pillars rested upon a flat surface at the bottom, but turned with a joint at the top, or were movable there in the direction of the length of the lever. Many of his experiments were made with defective specimens, which are not included, because such pieces should not be employed where they are exposed to

* 'Traité Analytique de la Résistance des Solides,' Table I.

much strain. By description and plates representing the most defective specimens, he has rendered it easy to ascertain the cause of many of the irregularities in his experiments. The least deflection only, with the weight that produced it, is given for each piece in the above Table; several other deflections were observed, but the first is the only one that is of use for the purpose of determining the strength of posts or columns. Most of the specimens bent in the direction of the diagonal, consequently they were curved both in the direction of the breadth and thickness. The deflection given above is that in the direction of the thickness, except in one case, which is Experiment 19; where the force cannot have been applied exactly in the direction of the axis. Some of the pieces were broken; in which case the weight that broke them is given. It is to be observed that the weight which broke the specimen, both in Girard's and Lamandé's experiments, was about twice that which produced the first deflection. But this is to be attributed more to the method of measurement than to any absolute law, as it has not been found to *hold good in the more recent experiments of Hodgkinson and others.*

M. Girard has not described the state of the wood when his trials were made, but it appears from a remark he makes on the 8th experiment, that it had been cut about fifteen months;* consequently it would not be very dry, as might be inferred from the weight of the cube foot given in the third column

* 'Traité Analytique de la Résistance des Solides,' Art. 235.

140. TABLE XVIII.—Of the RESISTANCE of SQUARE PILLARS of DANTZIC OAK, from a very good plank which had been cut up about 9 months.

(Hodgkinson.*)

Description.	Length in Inches.	Side of square in inches.	Deflection in inches.	Corresponding weight in lbs.	Breaking weight in lbs.	Mean breaking weight.	Remarks.
Uniform pillar rounded at the ends that the force might pass through the axis.	60·5	1·75	·09 ·17	2237 3197	3645	3197	Broke anglewise; it was slightly flattened at the end by the pressure.
Ditto ditto	60·5	1·75	·13	2141	2749		This was capped with iron at the ends, to prevent them from being crushed with the pressure. It bent and broke diagonally.
Uniform pillar, one end rounded and the other flat.	60·5	1·75	·09	2141			
	..	..	·11	3197			
	..	..	·13	3645			
	..	..	·16	4541			
	..	..	·20	5437			
	..	..	·27	6333			The rounded end was much crushed.
	..	..	·48	7229	7229	6109	
Ditto ditto	60·5	1·75	·06	1070			
	..	..	·08	1598			
	..	..	·11	2270			
	..	..	·15	2718			
	..	..	·17	3166			In this pillar the rounded end was capped with iron to prevent the end being crushed.
	..	..	·19	3614			
	..	..	·23	4093			
	..	..	·32	4541	4989		

* 'Phil. Transactions,' 1840.

TABLE XVIII.—*continued.*

Description.	Length in inches.	Side of square in inches.	Deflection in inches.	Corresponding weight in lbs.	Breaking weight in lbs.	Mean breaking weight.	Remarks.
Uniform pillar, both ends flat.	60·5	1·75	·02	3355			It was crushed at the end diagonally through the centre and sank down by flexure.
	..	..	·04	4795			
	..	..	·14	9499	10171		
Ditto ditto	60·5	1·75	..	..	11179		This sank by bending in the middle as usual; a portion of both ends was cracked.
Ditto ditto	60·5	1·75	·05	3211			With 8323 lbs. it sank down by bending, and when unloaded had taken a permanent set of ·52 inch.
	..	..	·09	5467		9625	
	..	..	·11	6139	8323		
Ditto ditto	60·5	1·75	·03	1070			This deflection was taken along the side, but it sank down diagonally; one end was slightly crushed.
	..	..	direction altered	3390			
	..	..	·02	4459			
	..	..	·04	6811			
	..	..	·07	8155			Most of these pillars changed the direction of flexure as they became loaded.
	..	..	·14	8827	8827		
Uniform pillar, flat at the ends and well bedded.	29·75	1·75	..	..	13083	..	It was crushed at the ends with the pressure, which caused it to break with a less weight than otherwise.
Uniform pillar, flat at the ends and well bedded.	30·25	1·75	..	..	14305	..	With less weight no cracking took place, but with this it wrinkled at the ends, bent, and sank down.
Uniform pillar, flat at the ends and well bedded.	48	1·75	..	..	9229	..	It was slightly bent before the weight was laid on; no cracking at the ends perceived before fracture by bending.
Uniform pillar, flat at the ends.	46·1	1·02	..	..	1791		These generally bent diagonally without crushing at the ends.
Ditto ditto	46·1	1·02	..	..	1791	1754	
Ditto ditto	46·1	1·02	..	..	1679		

TABLE XVIII.—*continued.*

Description.	Length in inches.	Side of square in inches.	Deflection in inches.	Corresponding weight in lbs.	Breaking weight in lbs	Mean breaking weight.	Remarks.
Uniform pillar, flat at the ends.	46·1	1·50	..	..	8069	7888	In the 1st and 2nd pillars there was no cracking at the ends previous to fracture The last was slightly split at one and by drying, and failed there.
Ditto ditto	46·1	1·50	..	..	8049		
Ditto ditto	46·1	1·50	..	..	7545		

Note.—In the above Table, by breaking weight is to be understood that which overcame the resistance of the pillar, and with which it sank down.

141. TABLE XIX.—Of the RESISTANCE to COMPRESSION of UNIFORM RECTANGULAR PILLARS of RED DEAL, flat at the ends, cut out of the same plank, the sectional area being in all cases nearly 4 inches.

(Hodgkinson.*)

Length.	Scantling.	Deflection.	Corresponding weight.	Weight with which it sank down.	Remarks.
inches.	in. in.	inches.	lbs.	lbs.	
58	2 × 2	·03	3254	..	Bent in direction of diagonal, one end crushed about one inch from bottom, and in the middle, two-thirds or three-fourths of the area being crippled.
..	.. ..	·10	6505		
..	.. ..	·12	8857		
..	.. ..	·17	11209	12385	
58	2 × 2	·09	4153		
..	.. ..	·12	6505		
..	.. ..	·15	8857		
..	.. ..	·32	11209	11601	Crushed as before.
58	2·9 × 1·4	·13	4153	..	Sunk by bending in the direction of the smaller side.
..	.. ..	·17	5329		
..	.. ..	·25	6505	7681	In another experiment a piece of the same size broke with somewhat less than this.
58	3·47 × 1·15	·42	4155	4349	Sunk by bending in the direction of the smaller side.

* 'Phil. Transactions,' 1840.

142. TABLE XX.—Of the RESISTANCE to COMPRESSION of LOGS of WHITE RIGA and RED DANTZIC FIR, each 20 feet long, the Ends cut square, and the Axis horizontal.

Scantling in inches:—Riga 13·5 × 13·0 at one end, 12·8 × 13·0 at other end, and 13·0 × 13·0 in the middle.
" " Dantzic 13·5 × 13·0 " 13·5 × 12·5 " " 13·5 × 13·2 "

(From experiments made by Mr. Kirkaldy for H. Carr, Esq., 1866.)

Description.	20,000 lbs.	40,000 lbs.	60,000 lbs.	80,000 lbs.	100,000 lbs.	120,000 lbs.	140,000 lbs.	150,000 lbs.	160,000 lbs.	180,000 lbs.	200,000 lbs.	220,000 lbs.	240,000 lbs.	250,000 lbs.	260,000 lbs.	280,000 lbs.	290,000 lbs.	300,000 lbs.	310,000 lbs.	320,000 lbs.	330,000 lbs.	Ultimate stress or breaking weight.
WHITE RIGA.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	lbs.
Compression	·032	·083	·122	·158	·191	·225	·258	·273	·292	·324	·358	·388	·420	·434	·455	·492	·508	·523	·540	·565	·642	331,260
Set..	..	..	..	..	·010	..	..	·014	..	..	·016	..	..	..	..	..	..	·022				
Deflection, horizontal..	..	..	..	..	·34	..	..	·41	..	..	·47	..	..	·53	..	..	..	·64				
" vertical ..	..	..	..	..	0	..	..	0	..	..	0	..	..	0	..	..	..	0				
RED DANTZIC.																						
Compression	·035	·088	·133	·170	·203	·232	·263	·276	·292	·318	·346	·370	·400	·414	·440	·488	·507	·548	..	..	..	309,120
Set..	..	..	..	..	..	..	..	..	..	..	·02	..	..	..	..	..	..	·033				
Deflection, horizontal..	..	..	..	..	·08	..	..	..	..	..	·19	..	..	·25	..	..	..	·47				
" vertical ..	..	..	..	..	·10	..	..	..	..	..	·22	..	..	·29	..	..	..	·55				

Note.—The Riga log gave way at knots 2 ft. 9 in. from middle, and the Red Dantzic at knots 9 in. from middle; the specimens were not very dry.

143. **Table XXI.**—Of the Resistance to Crushing in the Direction of the Fibre of Short Pillars of Different Kinds of Wood.

(Hodgkinson.*)

Description of Wood.	Strength per square inch in lbs.	Description of Wood.	Strength per square inch in lbs.
Alder	6831 to 6960	Oak (English)	6484 to 10058
Ash	8683 „ 9363	„ (Dantzic,	
Baywood	7518 „ 7518	very dry)	.. „ 7731
Beech	7733 „ 9363	Pine (pitch)	6790 „ 6790
American birch	.. „ 11663	„ yellow, full	
English birch	3297 „ 6402	of turpentine	5375 „ 5445
Cedar	5674 „ 5863	Pine (red)	5395 „ 7518
Crab	6499 „ 7148	Poplar	3107 „ 5124
Red deal	5748 „ 6586	Plum (wet)	3654
White deal	6781 „ 7293	„ (dry)	8241 „ 10493
Elder	7451 „ 9973	Sycamore	7082
Elm	.. „ 10331	Teak	.. „ 12101
Fir (Spruce)	6499 „ 6819	Larch (fallen	
Hornbeam	4533 „ 7289	two months)	3201 „ 5568
Mahogany	8198 „ 8198	Walnut	6063 „ 7227
Oak (Quebec)	4231 „ 5982	Willow	2898 „ 6128

The results in the first row of the second column were in each case a mean from about three experiments upon cylinders of wood, turned to be 1 inch diameter, and 2 inches long, flat at the ends. The wood was moderately dry, being such as is employed in making models for castings. The second row of figures gives the mean strength as before from similar specimens, after being turned and kept drying in a warm place two months longer. The lengths of the latter specimens were, in some instances, only 1 inch, which reduction would increase the strength a little. But the great difference frequently seen in the strength as given by the two rows of figures, shows strongly the effect of drying upon wood, and the great weakness of wet timber, *it not having half the strength of dry.*

Hodgkinson has shown the strength of short columns of the same material to be directly as the area of section.† This

* 'Phil. Transactions,' 1840. † 'Trans. of Brit. Association,' vol. vi.

seems easy to conceive, as bodies of the same nature always become crushed by sliding off in an angle, which is nearly constant; the height of the wedge, which would slide, being in timber usually about half the diameter or thickness of the specimen.

144. TABLE XXII.—Of the RESISTANCE to CRUSHING in the DIRECTION of the FIBRES of SHORT PILLARS of DIFFERENT KINDS of WOOD, chiefly GROWN in AMERICA; and of common use in that Country for the purpose of CONSTRUCTION. (Hatfield.*)

Description.	Specific gravity.	Crushing Force in lbs per square inch.	Description.	Specific gravity.	Crushing Force in lbs per square inch.
White wood	·397	2132	Maple	·574	6061
Mahogany (Baywood)	·439	3527	Cherry	·494	6477
Ash	·517	4175	White oak .. .	·774	6660
Spruce	·369	4199	Georgia pine ..	·613	6767
Chestnut	·491	4791	Locust	·762	7652
White pine	·388	4806	Live oak	·916	7936
Ohio pine	·586	4809	Mahogany, St. Domingo	·837	8280
Oak	·612	5316	Lignum vitæ ..	1·282	8650
Hemlock	·423	5400	Hickory	·877	9817
Black walnut ..	·421	5594			

The pieces of wood used in the experiments from which the above Table was compiled were of ordinary good quality, such as would be deemed proper to be used in framing. They were 2 inches long, and from 1 inch to 1½ inch square; some were thicker one way than the other. There were generally three specimens of each kind.

145. Hodgkinson has proved experimentally of rectangular pillars of timber, that of the greatest strength, where the length and quantity of material is the same, is the square.†

* 'American House Carpenter.

† 'Experimental Researches,' p. 351.

Of the Resistance of Long Pillars.

146. In long pillars, when the load tending to crush the material is small, the resistance to bending is nearly as the fourth power of the diameter directly; and as the square of the length inversely, as shown in the case of beams loaded transversely (Art. 100).

147. If the diameter of a cylindrical or the side of a square pillar be represented by D, the breadth and least thickness of a rectangular pillar by B and T, all in inches, the length by L in feet, and the weight that would cause the greatest amount of flexure consistent with safety by w in lbs., we have:

$$\frac{D^4 \times e}{L^2} = w \text{ for square pillars;} \qquad [19]$$

$$\frac{B \times T^3 \times e}{L^2} = w \text{ for rectangular pillars;} \qquad [20]$$

$$\frac{D^4 \times e}{1 \cdot 7\ L^2} = w \text{ for cylindrical pillars;} \qquad [21]$$

where e is a constant which varies with the kind of material.

148. In treating of the stiffness of beams to resist a cross strain, it was shown that a limit was necessary beyond which they should not deflect, in order to adapt them to the purpose of the carpenter. This limit was taken at $\frac{1}{40}$th of an inch for each foot of the total length.

In the case of pillars, or beams compressed in the direction of their length, and which are liable to accidental cross strains, often suddenly applied, this amount of deflection would be unsafe. Hence it is usual to limit the strain on pillars or beams under compression to that which would cause the smallest appreciable amount of deflection, or as it has been termed by the older writers on the Strength of Materials, "the point of first flexure." The determination of this point from experiment has been attended with much uncertainty. Hodgkinson states, with reference to the theory of

Euler, "that he has sought on many occasions, but without success, to determine experimentally some fixed point of the kind, but so far as he could see, flexure usually commences with very small weights, such as could be of little use to load pillars with in practice.*

There appears, however, to be a point beyond which a very rapid increase in the deflection takes place with a comparatively small increase in the load. It varies from $\frac{1}{3}$ to $\frac{1}{2}$ of the breaking weight in the experiments of Lamandé, Girard, *and Hodgkinson; but in the absence of sufficient data, by assuming the "first degree of flexure" to take place on the application of* $\frac{1}{10}$th of the breaking weight, a limit will be obtained beyond which it would not be safe to load pillars in practice.

149. In permanent structures it may be desirable to reduce this limit still further, owing to the tendency which timber has to warp when in long and slender pieces, so that the working load on a pillar as long as 60 diameters, without lateral support, should not be more than $\frac{1}{20}$th part of its calculated breaking weight.

150. To find the value of the constant e, we have from formula [19]

$$\frac{L^2 \times w}{D^4} = e. \qquad [22]$$

Applying this to the experiments of Lamandé on pillars of French oak 36 diameters in length (Table XVI.), and taking the load to cause "first flexure" at $\frac{1}{10}$th of the mean breaking weight given in the Table, we have:

Length in feet.	Side of Square in inches.	w in lbs.	Value of e.
6·375	2·176	777·5	1547

* 'Phil. Trans.,' 1840.

And from Hodgkinson's experiments on Dantzic oak of 30, 34, and 45 diameters in length (Table XVIII.), both ends being cut square:

Length in feet.	Side of Square in inches.	w in lbs.	Value of e.
3·8417	1·5	788·8	2230
5·0417	1·75	962·5	2609
3·8417	1·02	175·4	2392
		Mean ..	2410

And for pillars of red deal 29 diameters in length (Table XIX.), the ends cut square:

4·833	2·0	1199·3	1751

151. For other kinds of timber, in the absence of experiment, we have no means of obtaining the value of e, unless we assume with Dr. Young* that it varies according to the modulus of elasticity, as in the following Table:—

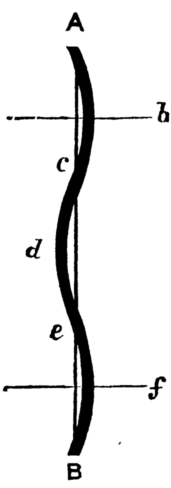
TABLE XXIII.—CONSTANT NUMBERS for LONG PILLARS.

Kind of Wood.	Modulus of Elasticity in lbs.	Values of e.
Ash	1,525,500	1840
Beech	1,316,000	1587
Chestnut	1,117,500	1384
Elm	1,343,000	1620
Fir, Riga	1,687,500	2035
„ Memel	1,957,750	2361
Larch	1,363,500	1645
Mahogany, Spanish ..	1,255,500	1514
„ Honduras ..	1,593,000	1921
Oak, English	1,714,500	2068
„ Dantzic	1,998,000	2410
Pine, Pitch	1,252,200	1510
„ Red	1,840,000	2219
„ Yellow	1,600,000	1930
Teak, Indian	2,167,074	2614
„ African	1,728,000	2084

* 'Nat. Philos.,' vol. ii.

152. It was noticed by Hodgkinson that the strength of long pillars was greatly influenced by the form and mode of fixing of the ends; when they were flat, the strength was about *three* times as great as when they were rounded; and when one end was flat and the other rounded, the strength was always an arithmetical mean between the strength of pillars of the same dimensions with both ends rounded and both ends flat. The fixing firmly of a pillar with flat ends somewhat increases the strength. Of these results the following explanation is given:

FIG. 44.



"Suppose a long uniform bar were bent by a pressure at its ends, so as to take the form A *b c d e f* B, Fig. 44, then all the curves A *b c*, *c d e*, *e f* B, separated by the straight line A *c e* B, would be equal, since the bar is supposed to be uniform.

"The curve having taken this form, suppose the points *b* and *f* to be rendered immovable by some firm fixings at those points. This done, it is evident that we may remove the parts near to A and B, without at all altering the curve *b c d e f* of the part of the pillar between *b* and *f*, and consider only that part. The part *b f*, which alone we shall have to consider, will be equally bent at all the points *b*, *d*, *f*. The parts *c* and *e*, too, are points of contrary flexure; consequently the pillar is not bent in them. These points are unconstrained, except by the pressure which forces them together; and the pillar might be reduced to any degree in them, provided they were not crushed or detruded by the compressing force.

"These points may then be considered as acting like the rounded ends in the pillars experimented upon; and the part *c d e* of the pillar, with its ends *c* and *e* supposed to be rounded, will be bearing the same weight as the whole pillar *b c d e f*, of double the length, with its ends *b f* firmly fixed."*

153. The conclusions to be drawn from these remarks are "that long uniform pillars, with both ends rounded, break in the middle only. Those with both ends flat break in three places—at the middle and near the ends. Those with one end rounded and one flat, break at about one-third of the distance from the rounded end."†

154. Increasing the thickness of pillars in the middle adds slightly to the strength.

155. Struts or compression beams, which have their own weight to support transversely, should have their depth somewhat in excess of the thickness.

Rules for the Resistance of Long Pillars to Flexure.

156. To find the greatest weight that may be placed on a square pillar of 30 diameters and upwards:

Rule XIV.—Multiply the fourth power of the side of the pillar in inches by the value of *e* (Table XXIII.), and divide by the square of the length in feet, and the quotient will be the weight required in pounds.

Example.—Required the weight in pounds that may be sustained by a pillar of Dantzic oak 10 feet long and 4 inches square. The value of *e* (Table XXIII.) being 2410,

$$\frac{2410 \times 4^4}{10^2} = \frac{2410 \times 256}{100} = 6169 \cdot 6 \text{ lbs.},$$

the weight required.

157. For cylindrical pillars proceed as in Rule XIV., but divide by 1·7 times the square of the length.

* 'Phil. Trans.,' 1840. † Ibid., 1857.

158. When the pillar is rectangular—

RULE XV.—Multiply the greater side by the cube of the least both in inches, and divide by the square of the length in feet, and the quotient multiplied by the value of e (Table XXIII.) will give the weight that the pillar will support in pounds.

Example.—What weight will a pillar of Red Pine 12 feet long support, the scantling being 6 inches by 4 inches, and the value of e (Table XXIII.) being 2219?

$$\frac{2219 \times 6 \times 4^3}{12^2} = \frac{2219 \times 6 \times 64}{144} = 5917 \cdot 3 \text{ lbs.},$$

the weight required.

OF THE STRENGTH OF PILLARS OF MEDIUM LENGTH.

159. When the length of a pillar is less than 30 diameters, the resistance to direct crushing becomes a considerable portion of the strength, and must therefore be taken into account in all calculations of the breaking weight.

160. The formula adopted for the most part by the engineers on the Continent is due to M. Love, who applied it to steel and other pillars;* it is similar to that introduced to the notice of English engineers by Professor Gordon, which is of the form

$$\frac{C\,S}{1 + f\,R^2} = W, \qquad [23]$$

where C is the weight in pounds that will crush a short prism 1 inch square (Table XXI.); S the area of a cross section of the pillar in square inches; $R = \frac{L}{T}$ the ratio of the length to the diameter or least thickness; f, a constant which

* 'Mémoire sur la Loi de Résistance des Piliers d'Acier.'

will depend upon the elasticity of the material; and W the weight in pounds that would break the pillar.

This formula, though apparently correct in theory, requires to be modified to accord with the result of experiments, thus:

$$\frac{C\,S}{1\cdot 1 + \frac{L^2}{2\cdot 9\,T^2}} = W \text{ for square or rectangular pillars.} \quad [24]$$

In which L is the length of the pillar in feet, and T the least thickness in inches.

161. *When the pillar is* CYLINDRICAL, *find the breaking weight as if it were square, and divide the result by* 1·7.

162. The following Table shows the application of the formula to the mean results of the experiments of Lamandé and Hodgkinson. The crushing strength of French oak being taken at 6336 lbs. to the square inch, and that of Dantzic oak at 7731 lbs. to the square inch:

TABLE XXIV.—SHOWING the AGREEMENT of the FORMULA with EXPERIMENT.

Length in feet.	Side of Square in inches.	Value of C S in lbs.	Calculated Breaking Weight in lbs. from Formula $W = \frac{C S}{1\cdot 1 + \frac{L^2}{2\cdot 9\, T^2}}$	Breaking Weight in lbs. from Experiment.
		FRENCH OAK (Lamandé).		
6·375	2·126	28,638	6,819	7,769
4·25	,,	,,	11,552	12,523
2·125	,,	,,	19,821	19,495
6·375	3·18	64,072	25,790	29,961
4·25	,,	,,	37,334	36,223
2·125	,,	,,	51,088	50,958
6·375	4·25	114,447	61,012	60,783
4·25	,,	,,	79,238	89,090
2·125	,,	,,	96,482	96,001
		DANTZIC OAK (Hodgkinson).		
2·52	1·75	23,676	13,045	14,305
2·48	,,	,,	13,209	13,083

163. Though the factor f in the formula would vary with the elasticity of the material, it has been taken at the constant value 2·9 for all kinds of wood, the strength of which is supposed to vary directly as C, or as the resistance to direct crushing per square inch.

Rules to ascertain the Strength of Pillars of Medium Length.

164. To find the weight that would break a square or rectangular pillar exceeding 5 diameters, but not exceeding 30 diameters in length.

Rule XVI.—Multiply the area of the cross section of the pillar in square inches by the weight in pounds that would crush a short prism of one inch square (Tables XXI. and XXII.), and divide the product by 1·1, added to the square of the length in feet, divided by 2·9 times the square of the least thickness in inches.

Example.—What load would break a pillar of Red Pine 10 feet long and 6 inches square, the weight that would crush a short piece 1 inch square being taken at 7518 lbs.?

$$\frac{7518 \times 36}{1 \cdot 1 + \dfrac{100}{2 \cdot 9 \times 36}} = \frac{270648}{2 \cdot 058} = 131510 \text{ lbs.},$$

or $51\frac{3}{4}$ tons nearly.

165. For Cylindrical Pillars: By dividing the breaking weight as in the last example by 1·7, the quotient will give the breaking weight of a cylindrical pillar of the same length, but 6 inches diameter instead of 6 inches square.

166. The safe or working load on pillars should not be greater than $\frac{1}{10}$th of the breaking weight, except those used for temporary purposes, in which case it might be increased to $\frac{1}{5}$th for pillars under 15 diameters, and to $\frac{1}{8}$th for those under 30 diameters.

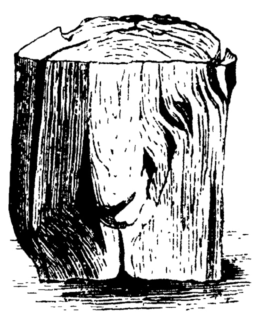
Of the Resistance of Short Pillars to Crushing in Direction of the Fibres.

167. In pillars of wood of less than about 5 diameters in length failure usually takes place by the separation and crippling of the fibres; it is the first appearance of this effect of the load that is usually noted by experimentalists as the crushing weight. In this sense the resistance of timber to crushing is less than the cohesive force, though with some materials it is greater.

Rondelet found that cubes of oak 1 inch in length were reduced more than one-third in height under a weight of from 5000 to 6000 lbs., and fir was reduced one-half in height by a pressure of from 6000 to 7000 lbs. per square inch.*

168. Wedges or short blocks of timber, though much reduced in height by the pressure, are nevertheless capable of resisting loads much beyond those which cause the fibres to separate or become crippled.

Fig. 45.



It is related by Mr. Edwin Clark † that on the occasion of the failure of one of the hydraulic presses used for lifting the Britannia Bridge into its position, the extremity of the tube fell on to a bed of soft deal planks piled loosely on each other about 4 feet high and about 12 feet by 5 feet in superficies; the tube being about 1½ inch above the planks, and compressing them through a space of about 7 inches. The bulk of the weight of half the

* 'L'Art de Bâtir,' tome iv.

† 'Britannia and Conway Tubular Bridges,' vol. i., p. 369.

tube, or about 1000 tons, was at the same time supported by an internal column of deal 14 inches high and 14 inches square, which continued to support a great part of the weight although crushed, as in Fig. 45, which shows a section of the block through the middle.

169. It has been supposed as regards timber that the force required to crush short specimens increased in a higher ratio than the area of their transverse section. This has not been borne out by Hodgkinson's experiments, and the following on Cylinders of Teak show the strength to be simply as the area of the section.

TABLE XXV.

	½ inch Diameter.	1 inch Diameter.	2 inches Diameter.
1	2.335	10,507	38,909
2	2.513	9,499	39,721
3	2,513	10,507	41,294
4	2,335	10,171	41,294
Means ..	2,439	10,171	40,301

170. When the length of Short pillars is increased the strength decreases as in the case of Long and Medium pillars, but in a less rapid ratio. Referring to the experiments of Lamandé (Table XVI.), we find that pillars of 2·125 feet long and 4·25 inches square, or 6 diameters in length, and containing 18·06 square inches in sectional area, failed with a mean load of 96,001 lbs., and taking the crushing weight of French oak at 6336 lbs. per square inch as before, the crushing load of a Short pillar of the same sectional area would be 114,428 lbs., or about 1·19 times that which caused a pillar of 6 diameters in length to fail. From this data we are enabled to obtain the strength of pillars under 5 diameters in length with sufficient accuracy for all practical purposes. Taking

C S as for Medium pillars, to represent the crushing strength where the length is 1 diameter, and W the breaking weight of pillars over 1 diameter in length as before, we have—

For Pillars of 2 Diameters in Length $W = \frac{C\,S}{1 \cdot 04}$

„ 3 „ „ $W = \frac{C\,S}{1 \cdot 08}$

„ 4 „ „ $W = \frac{C\,S}{1 \cdot 12}$

„ 5 „ „ $W = \frac{C\,S}{1 \cdot 16}$

The working load on Short pillars may be taken at *one-fifth* of the breaking weight.

Of the Resistance to Crushing across the Grain.

171. It frequently happens in framework that one piece is pressed against the side of another, and should the resistance which the latter offers to the force be insufficient, a degree of compression may take place that would produce considerable derangement, if not the total failure of the framing.

With the view of obtaining some information on this point the author prepared two pieces of good Memel fir, and placing the end of one piece against the side of the other, he found that a pressure of 900 lbs. to the square inch produced only a faint impression, but with 1000 lbs. the impression became very distinct. Therefore, 1000 lbs. per square inch is the greatest force that should be applied transversely to yellow fir.

The resistance varies with the position of the annual rings, for in other trials the impression was very distinct with 950 lbs. With a load of 1400 lbs. per square inch the impression on English oak appeared to be about the same as

was produced on Memel fir by 1000 lbs.; but the variation, owing to the position of the annual rings, was not so great.

172. The following Table by Mr. Hatfield shows the resistance of various woods used in America, to a pressure across the grain.*

TABLE XXVI.

Kind of Wood.	Specific gravity.	Force per square inch required to Crush the Fibres transversely $\frac{1}{20}$th inch deep.
		lbs.
Spruce	·369	500
White Wood	·397	600
White Pine	·388	600
Hemlock	·423	600
Chestnut	·491	950
Ohio Pine	·586	1250
Mahogany (Baywood)	·439	1300
Black Walnut	·421	1600
Georgia Pine	·613	1700
Oak	·612	1900
White Oak	·774	2000
Maple	·574	2050
Locust	·762	2100
Ash	·517	2300
Hickory	·877	3100
Mahogany (St. Domingo)	·837	4300
Live Oak	·916	5100
Lignum Vitæ	1·282	5800

173. It is obvious that the strength of a piece of framing is limited by the resistance of the parts which are pressed across the grain, and no greater force should be transmitted through any part which has its bearing on the side of another piece than the latter can support without being indented thereby.

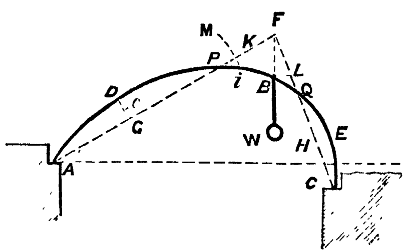
* 'American House Carpenter.'

OF THE PRESSURE ON CURVED RIBS.

174. Curved or arched ribs are adopted principally in the construction of bridges and roofs, where they are usually braced, so as not to depend too much on their own stiffness to resist cross strains. In order to determine what amount of bracing may be required, when it can be introduced, and to meet the cases where it cannot, as well as to determine the effect of any occasional force, as when a strong wind is straining a roof, or a heavy load passing over a bridge, it is necessary to consider first the case of a rib depending only on its own stiffness.

Let the irregular curve A B C (Fig. 46) represent the centre line of any rib, not necessarily of uniform strength throughout, resting on the immovable abutments at A and C, and supporting a weight W at B. The weight will tend to depress the rib and decrease its curvature at B, while it tends to raise it and increase the curvature at D, and probably also

FIG. 46.



at E. Between B and D, and B and E, there will be some points, P and Q, where the curvature has no tendency to change, that is, where the thrusts or reactions which support the weight W pass through A and C and cut the curve. The reactionary forces at A and C and the weight W balance each other, and therefore their directions must necessarily meet in

* By C. T. Guthrie, Esq.

some point F in the vertical line B F. The forces which are in the directions A F and C F we shall represent by f and f'. The segments A D P, C E Q will act as bent struts, and the segment P B Q as a bent lever. The stresses on A D P and C E Q are due entirely to the stiffness of the lever P B Q. So one-half the sum of the moments of the forces acting on the arc A D P cannot *exceed* the sum of the moments acting on the arc P B, so also for the arcs C E Q, and B Q; the moments, however, may be very much less, which is the case on the side C E B, or they may completely disappear. In determining the position of P and Q take the position of P, so that one-half the sum of the moments of the force f acting on the arc A D B may equal the sum of the moments on the arc P B, and on completing the figure ascertain whether the moments of f' on B Q exceed half those on C B; if they do, the figure is correctly drawn; if they do not, it shows that the arc C E B should have been dealt with in the first instance, and then the moments on P B would have been found to exceed $\frac{1}{2}$ those on A P. The forces $f\,f'$ can then be estimated by resolving the weight W in their directions. As the position of the weight W approaches C the point Q will also approach C, and under some conditions will coincide with it. The line F Q C may even fall outside the tangent to the arc at C, but it has been found in a variety of careful experiments on all sorts of curves, both regular and irregular, under every condition, that the equation of moments given above is strictly correct.

There is one point where the weight may be placed which will cause on both sides $\frac{1}{2}$ the sum of the moments on the haunch to equal the sum of the moments on the corresponding part of the crown. That point may be called the centre of equal moments. In a rib of irregular curvature it will generally be found nearer to one abutment than to the other. The maximum strain produced on a rib is when the weight

is placed in such a position with regard to the centre of equal moments that the direction of the thrust on the abutment passes through it.

To estimate the sum of the moments of a force acting on an arc, multiply the length of the arc into its mean distance from the direction of the force. Its mean distance is the distance of its centre of gravity, supposing it to be a line of uniform weight. Thus, if the arc A P were the segment of a circle, the sum of the moments of the force f acting on it would equal $\frac{2}{3} \times$ A D P $\times$ D G $\times f$, if its ver. sine does not exceed $\frac{1}{4}$ of its length

Again, in calculating the sum of the moments on the arc P B we may find the centre of gravity of the arc by taking it at $\frac{1}{3}$ the distance between the summit of the arc and the chord. The maximum strains on the arcs A D P, C E Q will be at D and E, the points most remote from the chords, and will be represented by $f \times$ D G and $f' \times$ E H. The maximum strain on the arc P B Q is at B, and will be represented by the moment $f \times$ B K or $f' \times$ B L.

When a curved rib is exposed to the effects of a force acting at an angle it may be treated in the same manner as if acted upon by a weight, and when it is acted upon by two or more forces the effect of each may be considered separately, and then added or deducted, as the case may require. But when the weights or forces are very numerous, or when the weight is continuous, other methods of finding the strains should be resorted to.

When the ends of a curved rib are rigidly secured in direction at the abutments, the lines of thrust no longer pass through them, but generally above, except the arc be the curve of equilibrium. The positions of P and Q are consequently altered, so that the moments on the arc cut off at A will equal $\frac{1}{2}$ the moments on the remainder of the arc up to

P, and will also equal the moments on P B. But the moments on the arc cut off at C cannot possibly exceed $\frac{1}{2}$ the moments on the remainder of the arc up to Q. If the form of the curve admits it, the latter, however, will equal twice those between B and Q.

When a curved rib is exposed to strains which materially change the direction of the thrusts at A and B, the abutments should be arranged to prevent lateral motion at the ends.

When it is desired that there should be no thrust at the abutments, the rib should be calculated as a bent beam.

When a rib is built up of a number of pieces, in calculating its strength allowance should be made for the imperfection of the fastenings.

FORMULÆ FOR THE STRENGTH OF CURVED RIBS.

175. In estimating the proper stiffness to be given to the haunches of curved ribs we know that the sum of the bending moments on them should not exceed those on straight beams equal in length to the chords of the ribs, and we know that the sum of the bending moments will vary as the length of the arc.

Let A be the length of the arc, L the length of the chord, v the ver. sine of the arc, and f a force acting in the direction of the chord. Take $\frac{2}{3}$ of v to represent the mean distance of the axis of the rib from the chord, and suppose the neutral axis to be coincident with the axis of the rib. Then we have for the sum of the moments on half the haunch $f\frac{A}{2} \times \frac{2}{3}v$, and for the moments on the half of a beam equal in length to the chord,

$$\frac{W}{2} \times \frac{L}{2} \times \frac{L}{4} \quad \therefore \quad \frac{W L^2}{16} = \frac{f A v}{3} \text{ or } W = \frac{16 f A v}{3 L^2}.$$

Substituting the above value of W in equation [8] (Art. 100)

$D^4 = W\,a\,L^2$, and putting L for the length A, we have for the strength at the haunches:

For square ribs .. $5 \cdot 33\ f\,L\,v\,a = D^4$. [25]

For rectangular ribs $5 \cdot 33\ f\,L\,v\,a = B\,T^3$ or $T\,B^3$. [26]

For cylindrical ribs $9 \cdot 066\,f\,L\,v\,a = D^4$. [27]

To calculate the strength at the crown. Let A be the length of the arc between the weight and the point P, and v its mean distance from the direction of the force; then equating the moments as before with those of a straight beam equal in length to the chord, we have

$$f\,A\,v = \frac{W}{2} \times \frac{L}{2} \times \frac{L}{4} \text{ or } W = \frac{f\,A\,v}{L^2}.$$

And substituting in equation [8], and again putting L for A, we have for the strength of the crown,

For square ribs .. $16\,f\,L\,v\,a = D^4$. [28]

For rectangular ribs $16\,f\,L\,v\,a = B\,T^3$. [29]

For cylindrical ribs $27 \cdot 2\,f\,L\,v\,a = T\,B^3$. [30]

Circular Ribs.

176. The most common form for an arched rib is a part of a circle. If its ver. sine does not exceed $\frac{1}{4}$ the length of its chord the point P may be taken at $\frac{3}{11}$ of the length of the arc B P D A (Fig. 46) from B without any sensible error. If it exceeds the above proportion the position of the point P should be corrected until the moments are equalized as described (Art. 174).

The maximum cross strain on a circular segmental rib is below the weight when the latter is placed so that the line of thrust passes through the centre of the crown, or when it is at $\frac{3}{8}$ of the length of the half-arc from that centre. The maximum cross strain at the haunch is also when the weight is placed in the same position.

When the ver. sine does not exceed $\frac{1}{4}$ of the length of the chord, the maximum strain at the crown is nearly double that at the haunch. But as $\frac{1}{2}$ the length of the arc at the haunch is equal to $\frac{4}{3}$ the length of the corresponding arc at *the crown, the scantling of the rib at the haunch will require to be made for stiffness more than $\frac{1}{2}$ the strength required* at the crown. (See Example.)

Example.—Let it be required to find the proper depth, at the centre and haunches, to give, to an oak rib 8″ thick, 20 feet span and 5 feet rise, to sustain a weight of 5 tons at any point; the curve being the segment of a circle.

1st. Suppose the weight is placed at the crown.

To find the strength at the crown we have formula [29]

$$B^3 = \frac{16\, f\, L\, a\, v}{T}.$$

By construction we find $f = 4\frac{1}{2}$ tons $= 10080$ lbs., $T = 8$, $v = 1'\cdot 5'' = 1\cdot 416$, $L = 3'\cdot 2\frac{1}{4}'' = 3\cdot 208$, and, from Table VI. (Art. 93), $a = \cdot 0119$.

$$\therefore\ B^3 = \frac{16 \times 10080 \times 3\cdot 208 \times \cdot 0119 \times 1\cdot 416}{8} = 1090.$$

$$\therefore\ B = 10\tfrac{1}{4}'' \text{ nearly.}$$

To find the strength at the haunches we have [26]

$$B^3 = \frac{5\cdot 33 \times f\, L\, a\, v}{T}.$$

By construction, $f = 10080$ lbs., $v = \cdot 7083$, $L = 8\cdot 5$, and $a = \cdot 0119$.

$$B^3 = \frac{5\cdot 33 \times 10080 \times 8\cdot 5 \times \cdot 0119 \times \cdot 7083}{8} = 481.$$

$$B = 8'' \text{ nearly.}$$

But in this case the maximum strains produced will be when the weight is situated at $\frac{3}{8}$ of the half-arc from the centre of the crown. Suppose the weight is placed in that position:

Then by construction we find $f = 7168$ lbs., $L = 4' \cdot 4\frac{1}{8}'' = 4 \cdot 344$, $v = 2' \cdot 7'' = 2 \cdot 5838$, $a = \cdot 0119$.

$$\therefore\ B^3 = \frac{16 f L a v}{T} = \frac{16 \times 7168 \times 4\cdot344 \times \cdot0119 \times 2\cdot5838}{8} = 1915.$$

$$B = 12\tfrac{1}{2}'' \text{ at the crown nearly.}$$

To find the strength at the haunch we have formula [26], $f = 7168$ *lbs.,* $L = 11 \cdot 7 = 11 \cdot 5833$, $v = 1 \cdot 3\frac{1}{2} = 1 \cdot 2916$ $a = \cdot 0119$.

$$B^3 = \frac{5 \cdot 33 \times f L a v}{T}$$

$$= \frac{5\cdot33 \times 7168 \times 11\cdot583 \times \cdot0119 \times 1\cdot2916}{8} = 850.$$

$$B = 9\tfrac{1}{2}'' \text{ nearly.}$$

In calculating the strength, therefore, of a uniform circular segmental rib draw the line of thrust through the axis at one springing, and through the centre of the crown, and let fall a perpendicular to represent the weight, cutting the axis at $\frac{3}{8}$ of the length of the half-arc from the crown. Then calculate the required strength by the formula [29].

The strength of a circular segmental rib varies imperceptibly with regard to its rise or curvature.

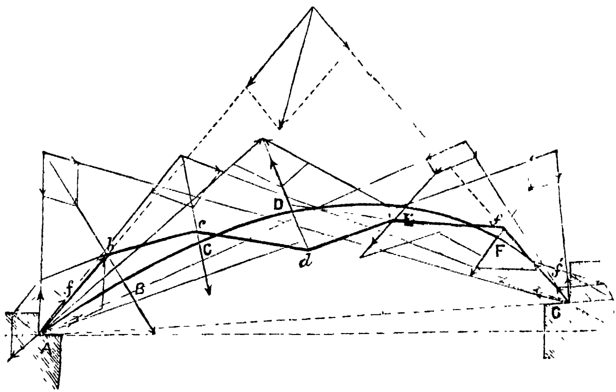
177. Next let us consider a rib of any curvature acted upon by any number of forces of various magnitudes and in different directions.

Let A B C D E F G (Fig. 47) be the centre line of any curved rib, with fixed abutments at A and G, acted upon by various forces represented in magnitude and direction by the lines B C D E F.

Resolve each force into two others, one through each abutment, taking care to choose the correct segment to divide so as to equate the moments. Then we have a collection of forces at each of the points A and G. Find the resultants $f f'$ of these collections; f and f' will represent in magnitude and

direction the thrusts on the abutments at A and L. Then commencing with f or f' construct the polygon of forces A $b\,c\,d\,e\,f$ G. The thrusts along its sides multiplied into their

Fig. 47.



distances from the axis of the rib will represent the moments tending to break the rib at various points, and the necessary scantlings may be found from the formulæ before given.

Of the Resilience of Beams.

178. A body in motion on being brought to a state of rest, exerts a greater force than the same body would if acting by its dead weight alone.

179. A beam resists the application of a moving force or of a load applied suddenly, by yielding until the resisting becomes equal to the straining force in the same manner as a spring, and if the beam is not sufficiently elastic it may break.

180. The power with which a beam resists the impact of a body in motion is termed its 'resilience,' and is simply proportional to the bulk or weight of the beam; thus a beam 10 feet long will support but half as great a pressure without

breaking as a beam of the same breadth and depth which is only 5 feet long, but it bears the impulse of a double weight striking against it with a given velocity, and will require that a given body should fall from a double height in order to break it.

The resistance of beams to impact is directly as the product of their strength to their ultimate deflection, and since the strength is as $\frac{B \times D^2}{L}$, and the ultimate deflection $\frac{L^2}{D}$, the power of resisting impact is as

$$\frac{B \times D^2}{L} \times \frac{L^2}{D} = B \times D \times L,$$

or simply as the solid contents or weight, B, D, and L representing the breadth, depth, and length respectively.*

It has been found by experiment on beams that the deflections are as the square roots of the heights through which the weight falls, or, in other words, the velocity of impact. Mr. Bevan made the following experiments on a beam 18 feet long between the supports, the weight of the beam being 127 lbs., and to bend it 1 inch in the middle required a steady load of 148 lbs. The weight of the falling body which produced the deflections given in the Table was 28 lbs. :—

TABLE XXVII.

Height fallen in inches.	Depression in inches.	Depression as the Square Root of the Fall.
12	1·25	1·25
24	1·66	1·77
36	2·35	2·17
48	2·62	2·5

* Clark's 'Conway and Britannia Tubular Bridges.'

181. The action of the rolling to which a railway bridge is subjected is intermediate, in those cases which occur in practice, between that of an absolutely sudden load and a perfectly gradual one.

In practice the additional strain arising, whether from the sudden application or swift motion of the load, is sufficiently provided for by making the factor of safety for the travelling part of the load about double that for the fixed part.*

SYNOPSIS OF THE FORMULÆ MOST USEFUL FOR ESTIMATING THE STRENGTH AND STIFFNESS OF TIMBER.

182. B = breadth in inches.

C = cohesive strength in lbs. per square inch, as in Tables II., III., IV., and XXVIII., or the *crushing force, as in Tables XXI., XXII., and XXVIII.*

D = depth in inches of rectangular, or = diameter of cylindrical beams.

Δ = deflection in inches.

L = length in feet.

S = area of cross section in square inches.

W = load in lbs.

a, c, e, &c., constant numbers to be found in the Tables.

Resistance to Tension.

W = C S = the weight in lbs. that would tear asunder a beam the area of whose section is S.

* Rankine, 'Civil Engineering, 1869.'

Resistance to Cross Strains.

Stiffness of Rectangular Beams supported at Both Ends and loaded in the Middle.

$$\Delta = \frac{a\,L^3\,W}{40\ B\ D^3} = \text{deflection in inches.}$$

When Δ is limited to $\frac{1}{40}$th of an inch to a foot we have

$$D = \sqrt[3]{\frac{a\,L^2\,W}{B}} = \text{depth in inches.}$$

$$D = \sqrt[3]{\frac{a\,L^2\,W\cos.c}{B}} = \text{ditto when the beam is inclined,}$$

c being the angle which it makes with the horizontal.

$$B = \frac{a\,L^2\,W}{D^3} = \text{breadth in inches.}$$

$$W = \frac{B\,D^3}{a\,L^2} = \text{weight in lbs. sustained by a beam without yielding more than } \tfrac{1}{40} \text{ inch per foot.}$$

$$W = \frac{B\,D^3}{a\,L^2\cos.c} = \text{ditto when the beam is inclined.}$$

When W is uniformly distributed the deflection is only $\frac{5}{8}$ths of that caused by a central load. (Art. 111.)

When the beam is fixed at one end and loaded at the other, the deflection is sixteen times greater than when the beam is merely supported at the ends. (Art. 112.)

Strength of Rectangular Beams supported at Both Ends and loaded in the Middle.

$$W = \frac{c\,B\,D^2}{L} = \text{breaking weight in lbs.}$$

$$W = \frac{c\,B\,D^2}{L\cos.c} = \text{ditto when the beam is inclined.}$$

Calling W the load in the middle as in the two last formulæ, we have for the breaking weight of—

Beams *fixed* at both ends and loaded in the middle	$W \times 1\frac{1}{2}$
Ditto *fixed* at one end and loaded at the other	$W \times \frac{1}{4}$
Ditto *supported* at both ends and the load uniformly distributed	$W \times 2$
Ditto ditto loaded at any point, m and n representing the segments into which the beam is divided by the load	$W \times \frac{L}{4\,m\,n}$.

The strength and stiffness of a *cylindrical* beam are to those of a square one as 10 is to 17. (Arts. 108 and 122.)

Resistance to Compression.

Stiffness of Beams or Pillars above 30 *diameters in length.*

$$w = \frac{D^4\,e}{L^2} = \text{weight in lbs. for square pillars to resist flexure.}$$

$$w = \frac{B\,T^3\,e}{L^2} = \text{ditto for rectangular pillars.}$$

$$w = \frac{D^4\,e}{1 \cdot 7\,L^2} = \text{ditto for cylindrical pillars}$$

T being the least thickness in inches.

Strength of Beams or Pillars less than 30 *diameters in length.*

$$W = \frac{C\,S}{1{\cdot}1 + \frac{L^2}{2 \cdot 9\,T^2}} = \text{breaking weight in lbs.}$$

The strength of cylindrical beams or pillars is to square ones as 10 is to 17.

TABLE XXVIII.—A SELECTION of CONSTANT NUMBERS for the *STRENGTH AND STIFFNESS of BEAMS and PILLARS.*

Name of Timber.	Cohesive Force per sq. inch in lbs.	Transverse Strains.		Compression.	
		a Stiffness.	*c* Strength.	*e* Flexure.	C Crushing per sq. in. in lbs.
Ash	16,800	·0105	675	1840	8,683
Beech	11,500	·0128	519	1587	7,733
Elm	14,400	·0212	338	1620	8,265
Fir, Riga	12,600	·0114	359	2035	5,400
„ Memel	..	·0089	545	2361	5,400
Larch	8,900	·0126	300	1645	3,201
Mahogany	8,000	·0109	450	1921	8,198
Oak, English	12,000	·0119	557	2068	6,484
„ Dantzic	12,000	·0105	486	2410	6,185
„ Canada	12,000	·009	589	..	4,231
Pine, American Red	10,000	·0148	417	2219	5,395
„ „ Yellow ..	..	·019	383	1930	5,375
Teak	15,000	·0076	821	2614	10,081

The constants in the above Table are based on experiments made by the most eminent authorities. The specimens used by them were, however, of small scantling and of a quality superior to that which would be found throughout the whole substance of a large beam. Among the experiments made for the Britannia Bridge were two balks of American red pine selected from the scaffolding intended for the bridge. Each balk was 12 inches square and 15 feet long between the supports. The breaking weight in the middle, as deduced from experiments on small pieces, was 23 tons nearly, yet one of the balks broke with 13·24 tons, and the other with 14·82 tons.

A comparison of Hodgkinson's and Kirkaldy's experiments on pillars of wood will show a similar discrepancy.

It would therefore appear that the application of rules and general formulæ to the designs of the carpenter requires considerable judgment and practical knowledge.

FORM TO BE GIVEN TO BEAMS EXPOSED TO A TRANSVERSE STRAIN, SO THAT THEY MAY BE OF UNIFORM STRENGTH.

Beams fixed at One End.

183. A solid rectangular beam of uniform depth fixed at one end and loaded at the other, should be on plan in the shape of a triangle, as Fig. 48.

FIG. 48.

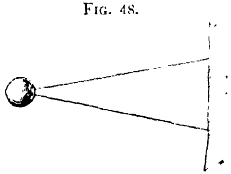
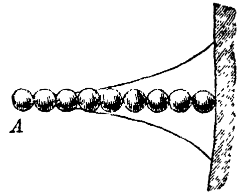


FIG. 49.



184. If the beam be loaded *uniformly* it will still be triangular on plan, but the sides of the triangle instead of being straight lines will be parabolas whose common vertex is at A (Fig. 49).

185. When the breadth is constant and the top is horizontal, the depth should increase from the point of application of the weight towards the support in the form of a parabolic curve, whose vertex is at A and axis horizontal (Fig. 50).

FIG. 50.

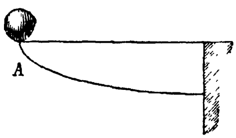
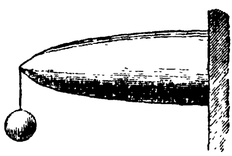


FIG. 51.



With a uniform load, when the breadth is constant the elevation of the beam will be triangular.

186. In a solid round beam fixed at one end and loaded at the other, the form required for uniform strength is that

generated by the revolution of a cubic parabola round a horizontal axis (Fig. 51).

Beams supported at Both Ends.

187. When the depth of a solid rectangular beam is uniform, the breadth will vary in the form of two triangles with their vertices at the points of support and their bases at the point of application of the load (Fig. 52).

FIG. 52.

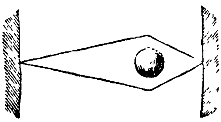
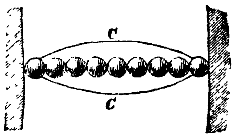


FIG. 53.



188. *If the beam be loaded uniformly and the depth be constant, the breadth will vary in the form of two parabolas* which overlap, and whose vertices are in the middle of the beam C, C (Fig. 53).

189. When the breadth of a beam loaded in the middle is constant and the top horizontal, the bottom edge will be in the form of two parabolic curves which intersect at the point of application of the load, and have their axes horizontal and their vertices at the points of support (Fig. 54).

FIG. 54.

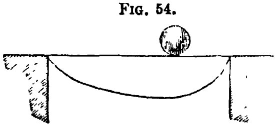
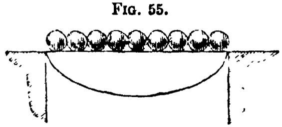


FIG. 55.



190. If the beam be uniformly loaded the depth will vary in the form of a semi-ellipse, the top being horizontal (Fig. 55).

Note.—In the application of the Rules for calculating the Stiffness and Strength of Beams, it should be borne in mind that where the

length is short in proportion to the depth, the load required to produce a deflection of $\frac{1}{40}$th of an inch to a foot may exceed the safe load calculated by the Rules for Strength; and when the length is great in proportion to the depth there may be a deficiency of Stiffness, although the load may not exceed the calculated safe load to resist breaking:—

If F represents the usual factor of the Breaking Weight for Safety, a and c the constants for Stiffness and Strength, as in the foregoing tables, B and D the breadth and depth in inches, and L the length in feet. We have, when the beam is both *stiff* enough and *strong* enough,

$$\frac{D}{L} = \frac{a\,c}{F}$$

Example.—For Riga fir, Table VII., gives $a = \cdot 0115$, and Table XIV. gives $c = 530$, and if F be assumed $= 5$, we have—

$\frac{D}{L} = \frac{\cdot 0115 \times 530}{5} = \frac{6}{5}$ nearly i.e. the depth should be $1\frac{1}{5}$ of an inch for every foot in length.

When the load is distributed

$$\frac{D}{L} = \frac{5}{4}\,\frac{a\,c}{F}$$

Example.—Take the numerical factors as before, then—

$\frac{D}{L} = \frac{5 \times \cdot 0115 \times 530}{4 \times 5} = 1 \cdot 52$, or about $1\frac{1}{2}$ inch in depth for every foot in length.

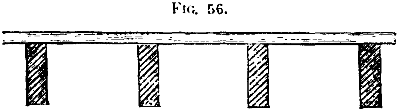
SECTION III.

OF THE CONSTRUCTION OF FLOORS.

191. *The timbers which support the flooring boards and ceiling of a room underneath are called, in carpentry, the naked flooring.* There are several kinds of naked flooring, but they may be all comprised under the three following heads, *viz.* single-joisted floors, double floors, and framed floors.

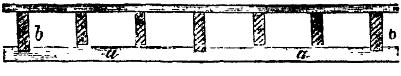
1st. SINGLE-JOISTED FLOORS. A single-joisted floor consists of only one series of joists, as shown in Fig. 56, which is a section across the joists.

FIG. 56.



Sometimes every third or fourth joist is made deeper, and the ceiling joists are fixed to the deep joists, crossing them at right angles. This is an improvement where there is not space for a double floor. Fig. 57 shows a section of this

FIG. 57.



kind of floor. The depth is increased very little, and sounds will not pass so freely as in a single-joisted floor; besides, the

ceiling will stand better. The ceiling joists, *a*, *a*, are notched and nailed to the deep joists, *b*, *b*, *b*.

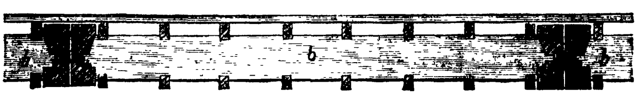
192. 2ndly. DOUBLE FLOORS. A double floor consists of three tiers of joists, *viz.* binding joists, bridging joists, and ceiling joists; the binding joists are the chief support of the floor, and the bridging joists are notched upon the upper side of them; the ceiling joists are either notched to the under side, or framed between with chased mortises; the best method, however, is to notch them. Fig. 58 shows a section

FIG. 58.

of a double floor across the binding joists, *b*, *b*, *b*. The bridging joists, *d*, *d*, are notched over, and the ceiling joists, *a*, *a*, are notched under the binding joists.

193. 3rdly. FRAMED FLOORS differ from double floors only in having the binding joists framed into large pieces of timber, called girders. Fig. 59 shows a section across the girders of a framed floor, where *b*, *b*, *b*, are the binding joists.

FIG. 59.



Single joisting makes a much stronger floor, with the same quantity of timber, than a double or framed floor, and may be constructed with equal facility for the same extent of bearing; but the ceilings are more liable to cracks and irregularities; consequently, single-joisted floors of long bearings should only be used in inferior buildings.

When it is desirable to have a perfect ceiling, a double floor should be used; but when the bearing is long, a framed floor becomes the most convenient. The following experiment was made by Professor Robison on the comparative strength of framed and single-joisted floors.

194. Two models were made 18 inches square; one consisted of single joists, the other framed with girders, binding joists, bridging and ceiling joists; the single joists of one contained the same quantity of timber as the girders alone of the other. They were placed in a wooden trunk 18 inches square within, having a strong projection on the inside for the floors to rest on; and small shot was gradually poured over.

The single-joisted floor broke down with 487 pounds, the framed floor with 327 pounds.* The difference probably would not be so great on a large scale, because the girders would not be weakened so much by mortises. This is only one of many cases where apparent strength has turned out to be real weakness; and it shows how necessary it is to distinguish the parts which really support a load from those which only appear to do so.

One cwt. per superficial foot is an ample allowance for the probable load on an ordinary dwelling-house floor, exclusive of the weight of the floor itself. And 2 cwt. per superficial foot is sufficient in most cases for warehouse and factory floors.

Mr. Page, the engineer of the Chelsea Suspension Bridge, found the weight of a crowd of men closely packed to be 84 lbs. per superficial foot.†

Of Single-joisted Floors.

195. In order to make a strong floor with a small quantity of timber, the joists should be thin and deep; but a certain

* 'Encyclopædia Britannica,' art. Roof.

† 'Transactions, Society of Engineers,' 1863.

degree of thickness is necessary for the purpose of nailing the boards, and two inches is perhaps as thin as the joists ought to be made, though sometimes they are made thinner.

To find the depth of a joist when the length of bearing and breadth are given, the distance apart from middle to *middle being 12 inches.*

*Rule.—Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 2·2 for fir, or 2·3 for oak, will give the depth in inches.**

Example.—Required the proper depth for a fir joist, the bearing being 12 feet and the breadth 2 inches?

$\frac{12 \times 12}{2} = 72$, the cube root of which is $4 \cdot 16$; therefore $4 \cdot 16 \times 2 \cdot 2 = 9 \cdot 152$ inches, the depth required; or $9\frac{1}{4}$ inches nearly.

The scantling of single joists should be increased when they are used for the support of warehouse, factory, or other floors which have to sustain exceptionally heavy loads.

On account of flues, fire-places, and other causes, it often happens that the joists cannot have a bearing on the wall. In such cases a piece of timber, called a *trimmer*, is framed between two of the nearest joists that have a bearing on the wall. Into this trimmer the ends of the joints to be supported are mortised. This operation is called *trimming*. The scantlings of trimmers may be found by the same rule as

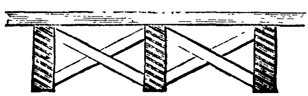
* The constant numbers in this, and in all the rules for flooring and roofing, are derived from the scantlings of timbers that were found to be sufficiently strong; this the author considered to be the best method of obtaining those numbers, because it is difficult to calculate the weight that a floor has to support, yet it is easy to ascertain whether a floor be sufficiently stiff or not after it is executed. These comparisons have not been made from single observations, but from various ones on bearings of different lengths. The constant numbers are taken higher for oak, because the oak is seldom straight grained, and very subject to warp.

those for binding joists (Case 2, Art. 210), the length of the joists framed into the trimmer being equivalent to the distance apart in binding joists.

The two joists which support the trimmer are called *trimming joists*, and they should be stronger than the common joists. *In general it will be sufficient to add one-eighth of an inch to the thickness of a trimming joist for each joist supported by the trimmer. Thus, if the thickness of the common* joists be 2 inches, and a trimmer supports four joists, then add four-eighths, or half an inch; that is, make the trimming joists each $2\frac{1}{2}$ inches in thickness.

When the bearing exceeds 8 feet, single joisting should be strutted between the joists to prevent them turning or twisting sideways, and also to stiffen the floor; when the bearing exceeds 12 feet, two rows of struts will be necessary; and so on, adding another row of struts for each increase of 4 feet in bearing. These struts should be in a continued line across the floor; short ends of boards, put in moderately tight, and nearly of the depth of the joists, are sufficient; such pieces simply nailed are better than keys mortised into the joists, because they require less labour, and do not weaken the joists with mortises. The best method of strutting is that shown in Fig. 60, which is called "Herringbone Strutting." The

FIG. 60.



pieces are usually about 2 inches square, and are spiked at the ends to the joists; struts of this description do not become loose in case of the shrinking of the joists. The well fitting of the struts is an essential part in making a good ceiling.

For common purposes single joisting may be used to any

extent where timber can be obtained deep enough; but where it is desirable to have a perfect ceiling, the bearing should not exceed 12 feet.

Where it is desirable to prevent the passage of sound, a framed floor is necessary; but in a single-joisted floor it may be reduced by putting strips of list or thin slices of cork between the upper edge of the joists and the floor boards.

Of Framed Floors.

Girders.

196. The girders are the chief support of a framed floor, but their depth is often limited by the size of the timber; therefore, the method of finding the scantling should be divided into two cases.

Case 1.—To find the depth of a girder for the floor of a dwelling-house when the length of bearing and breadth are given.

Rule.—Divide the square of the length in feet by the breadth in inches; and the cube root of the quotient multiplied by 4·2 for fir, or by 4·34 for oak, will give the depth required in inches.

197. *Case* 2.—To find the breadth when the length of bearing and depth are given.

Rule.—Divide the square of the length in feet by the cube of the depth in inches; and the quotient multiplied by 74 for fir, or by 82 for oak, will give the breadth in inches.

Example to Case 2.—Let the bearing be 20 feet, and the depth 13 inches; to find the breadth, so that the girder shall be sufficiently stiff.

The cube of the depth is 2197, and the square of the length is 400; therefore $\frac{400}{2197} \times 74 = 13 \cdot 47$ inches, the breadth required.

In these rules the girders are supposed to be 10 feet apart, which ought never be exceeded; but should the distance apart be less or more than 10 feet, the breadth of the girder should be made in proportion.

Girders for long bearings should always be made as deep as the timber can be obtained; an inch or two taken from the height of a room is of little consequence compared with a ceiling disfigured with cracks, besides the inconvenience of not being able to move without shaking everything in the room.

For warehouse or other floors which have to sustain heavy loads, the strength of the girders should be calculated for each particular case by the Rules given in Arts. 102 to 107, and 182, Sect. II.

198. When the breadth of a girder is considerable, it is often sawn down the middle and bolted together with the sawn sides outwards; the girders in Fig. 59 are supposed to be done in this manner. This is an excellent method, as it not only gives an opportunity of examining the centre of the tree, which in large trees is often in a state of decay, but also reduces the timber to a smaller scantling, by which means it dries sooner, and is less liable to rot. Thin slips should be put between the halves or flitches to allow the air to circulate freely between them. It is generally imagined that a girder is strengthened when cut down, reversed, and bolted together again; it is in fact weakened by the operation, but the method is recommended for the reasons stated.

Others suppose that girders are cut down merely for the purpose of equalizing their stiffness; but admitting a girder to be bent considerably, the difference between the deflections at any two points equally distant from the middle would not be sensible in those of the usual form. The person who first practised the method of cutting girders down the middle undoubtedly did it with the view of preserving, and not of

stiffening them. We find that Vitruvius, the oldest author extant on architecture, directs a space of two fingers' breadth to be left between the beams for forming the architrave over columns, *in order that the air may circulate between and* prevent decay.* Every one must have observed that decay begins at the joints and other places where the pieces are neither perfectly close nor yet sufficiently open to allow any dampness to evaporate.

199. When the bearing exceeds about 22 feet, it is very difficult to obtain timber large enough for girders; in such cases it is usual to truss them. The methods formerly adopted for that purpose are shown in Figs. 61 and 62,

FIG. 61.

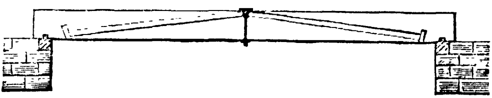


FIG. 62.

which have the appearance of much ingenuity; but, in reality, they are of very little use. If a girder of fir be trussed with oak, all the strength that can possibly be gained consists merely in the difference of compressibility between the two, which is very small indeed; and unless the truss be extremely well fitted at the abutments, it would be much stronger without trussing. All the apparent stiffness is obtained by cambering the beam, which cripples and injures the natural elasticity of the timber; and the continual spring, from the motion of the floor, upon parts already crippled, as

* 'Vitruvius,' lib. iv., cap. 7.

may easily be conceived, will soon render the truss a useless burden upon the beam. This fact has long been known to many of our best carpenters, and has caused them to seek a remedy in iron trusses, which are quite as bad as the former, unless there be an iron tie to prevent the truss from spreading, for the failure is occasioned by the enormous compression applied to a small surface of timber at the abutments.

200. Barlow made some experiments on trusses similar to Figs. 61 and 62, the results of which are shown in the following Table, which confirm the above remarks.

Description.	Length of bearing		Weight	Deflection produced by the weight.
	feet	inches.	lbs.	
Two oak trusses meeting against a king bolt in the centre, with plate bolts at the abutments	4	2	600	0·87
Piece of the same size, without trusses	4	2	600	1·00
Three trusses, with two queen bolts with plate bolts at the abutments	5	8	500	2·25
Piece of the same size, without trusses	5	8	500	1·55

The pieces were 2 inches deep and $1\frac{7}{8}$ inch in breadth. In the experiment with the girder having a king bolt and two truss-pieces, there appears to be a slight advantage in trussing; but in that with three lengths, it was much weaker than the untrussed piece.*

The attempt to make a solid beam stronger in the same bulk, without using a material stronger than the beam itself, is ridiculous; yet such has been the aim of most writers on Carpentry.†

* See Barlow's 'Essay on the Strength and Stress of Timber.'

† See Smith's 'Carpenter's Companion,' Price's 'British Carpenter,' and Langley's 'Builder's Complete Assistant.'

Though the mode of trussing girders above mentioned cannot be relied upon, nor, indeed, any other timber truss that is made within the depth of the beam; yet, by adding to the depth, there are several methods that may be applied with success in extending the bearing of timber girders. But where the depth is limited, and the bearing considerable, or where a great weight has to be supported, iron must be employed, and the best for the purpose is wrought iron, which is not so liable to flaws, or to fracture from the fall of heavy loads or other causes, as cast iron.

201. A method of strengthening a timber girder without increasing the depth is shown in Fig. 63, where a plate of wrought iron is bolted on each side of a timber beam, or as shown in Fig. 64, where a single plate or flitch of iron *is placed between two planks or a beam cut down the middle and reversed.*

Fig. 63.

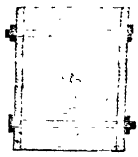
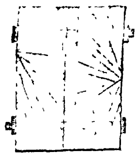


Fig. 64.



It might be questioned whether iron and wood thus combined would be effective, owing to the difference in the resisting powers of the two materials; but from the following experiments, which were made at the Royal Arsenal, Woolwich, in 1859, it would appear that there is some advantage as regards strength in a combination of this kind.

The beams were of fir, $18\frac{1}{2}$ feet long, resting on two supports placed 17 feet apart.

EXP. No. 1.—TWO MEMEL DEALS, each 9 in. × 3 in., laid side by side as in Fig. 65.

FIG. 65.

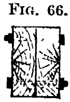
	Load.	Deflection.		Remarks.
		At middle.	At 4 ft. 3 in. from middle.	
	lbs.	in.	in.	
Load equally distributed over the length.	2,310	·510	·375	Broke in middle with 13,102 lbs.
	4,208	1·010	·750	
	6,534	1·375	1·125	
	8,294	2·250	1·625	
	10,542	3·010	2·250	
	12,235	4·000	3·000	
	13,102	4·500	..	

EXP. No. 2.—TWO MEMEL DEALS, 9 in. × 3 in., placed as in Exp. No. 1.

	Load.	Deflection.		Remarks.
		At middle.	At 4 ft. 3 in. from middle.	
	lbs.	in.	in.	
Load placed on middle of length.	2,271	1·250	·760	Broke in middle with 6,800 lbs.
	4,597	2·500	1·750	
	6,166	3·500	2·750	
	6,800	4·500	3·000	

EXP. No. 3.—TWO MEMEL DEALS, 9 in. × 3 in., as in No. 1, but bolted together as in Fig. 66 with twelve wrought-iron bolts, ¾ in. diameter.

FIG. 66.



	Load.	Deflection.		Remarks.
		At middle.	At 4 ft 3 in. from middle.	
	lbs.	in.	in.	
Load equally distributed over the length.	2,316	·510	·375	Broke in middle with 13,503 lbs.
	4,204	1·000	·750	
	6,466	1·625	1·250	
	8,186	2·010	1·625	
	10,441	2·750	2·010	
	12,116	3·250	2·500	
	13,503	4·000	..	

Exp. No. 4.—Two Memel Deals, 9 in. × 3 in. as last, but with a plate of wrought iron 9 in. deep × ½ in. thick placed between the deals, as Fig. 64, and bolted with eleven ¾-in. bolts

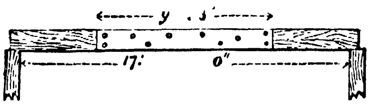
	Load.	Deflection.		Remarks.
		At middle.	At 4 ft. 3 in. from middle.	
	lbs.	in.	in.	
Load equally distributed over the length.	5,592	·625	·375	Broke in middle with 34,862 lbs.
	9,293	1·000	·750	
	14,692	1·500	1·125	
	16,617	1·750	1·375	Both the timber and iron snapped asunder.
	18,858	2·000	1·500	
	20,734	2·125	1·635	
	22,993	2·375	1·750	
	24,696	2·635	1·990	
	26,628	2·750	2·125	
	28,392	3·125	2·375	
	30,802	3·510	2·760	
	34,862	4·750	3·500	

Exp. No. 5.—Two Memel Deals, 9 in. × 3 in., with wrought-iron plate ½ in. thick, as last.

	Load	Deflection		Remarks
		At middle	At 4 ft 3 in. from middle.	
	lbs.	in.	in	
Load on middle of length.	4,759	·740	·490	Broke in the middle with 18,079 lbs.
	7,148	1·000	·740	
	10,148	1·500	1·000	
	13,372	2·333	1·500	
	16,491	3·500	2·500	
	18,079	4·500	3·broke.	

EXP. No. 6.—BEAM as No. 4, but with the iron flitch only 9 ft. 3 in. long, or about half the length of the beam, as Fig. 67.

FIG. 67



	Load.	Deflection. At middle.	Deflection. At 4 ft. 3 in. from middle.	Remarks.
	lbs.	in.	in.	
Load equally distributed over the length.	5,881	·750	·625	Broke with 21,566 lbs. at the bolt-holes at one end of the iron flitch. The iron being uninjured.
	9,568	1·500	1·250	
	14,699	2·250	2·000	
	17,509	2·750	2·250	
	19,721	3·250	2·750	
	21,566	Broke suddenly.		

EXP. No. 7.—BEAM SAME AS LAST.

	Load.	Deflection. At middle.	Deflection. At 4 ft. 3 in. from middle.	Remarks.
	lbs.	in.	in.	
Load on middle of length.	2,248	·500	·375	Broke with 14,873 lbs. at one end of iron flitch, which was uninjured.
	4,459	1·000	·625	
	6,715	1·500	1·250	
	9,012	2·000	1·500	
	11,273	2·750	2·000	
	13,413	3·500	2·750	
	14,873	Broke.		

Exp. No. 8.—Rectangular Beam of Baltic Fir, 9 in. broad × 12 in. deep, in one piece, 18 ft. 6 in. long and 17 ft. between the supports.

	Load.	Deflection. At middle.	Deflection. At 4 ft. 3 in. from middle.	Remarks.
	lbs.	in.	in.	
Load equally distributed over the length.	5,503	·500	·375	Broke with 27,076 lbs. in two places near the middle, at a cluster of small knots.
	9,147	1·000	·750	
	14,586	1·500	1·000	
	17,326	1·750	1·250	
	19,690	2·000	1·500	
	21,530	2·500	2·000	
	23,515	2·875	2·250	
	25,494	3·250	2·750	
	27,076	3·740	3·240	

Exp. No. 9.—Rectangular Beam of Baltic Fir, in one piece, 6 in. broad × 9 in. deep, the length same as last.

	Load.	Deflection. At middle.	Deflection. At 4 ft. 3 in. from middle.	Remarks.
	lbs.	in.	in	
Load equally distributed over the length.	5,836	1 500	1·250	Broke with 11,879 lbs. near the middle, at a cluster of small knots.
	8,615	2 625	2·000	
	10,619	3·500	2·500	
	11,879	Broke.		

The following formula, taken from Hurst's 'Surveyors' Handbook,' will give the breaking weight of beams with iron flitches placed as in Figs. 63 and 64:

$$W = \frac{D^2}{L} (C\,B + 30\,t).$$

where B and D are the breadth and depth of the wood in inches, t the thickness of the iron flitch in inches, L the

length between the supports in feet, and W the breaking weight at the middle in cwts.; C, a constant for the kind of timber as follows:

	Values of C.
Teak	4·006
English or Baltic Oak	3·662
Canadian Oak	3·173
Baltic Fir	3·024
American Pine	2·774
Cedar	2·219

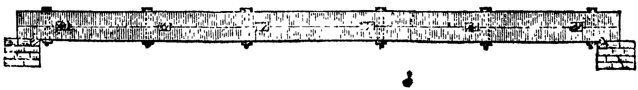
The thickness of the iron flitch will depend upon the relative degrees of resistance of the iron and wood; in the rule it has been assumed at one-twelfth. The best proportion in each case requires, however, to be determined by experiment.

202. But it may happen that iron cannot be obtained except at considerable expense. It is therefore proper to show how it could be done without, particularly when we have the means of increasing the depth of the floor.

203. The principle of constructing deep girders is the same as that of building beams, and when properly done they may be made as strong as any truss of equal depth.

The most simple method consists in bolting two pieces together, with keys between, to prevent the parts sliding upon each other. The joints should be at or near the middle of the depth. Fig. 68 shows a beam put together in this

FIG. 68.

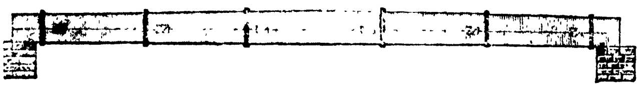


manner. The thickness of all the keys added together should be somewhat greater than one-third more than the whole depth of the girder; and, if they are made of hard wood, as

they ought to be, the breadth should be about twice the thickness.

204. Fig. 69 is another girder of the same construction, except that it is held together with hoops instead of bolts.

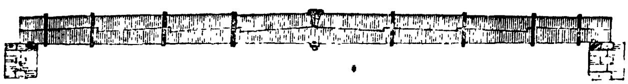
FIG. 69.



The girder being cut so as to be smaller towards the ends will admit of these hoops being driven on till they are perfectly tight, and therefore make a very firm and simple connection.

205. In Fig. 70 the parts are tabled or indented together instead of being keyed, and a king bolt is added to tighten

FIG. 70.



the joints; the upper part of the girder being in two pieces. The depth of all the indents added together should not be less than two-thirds of the whole depth of the girder.*

206. Another method of constructing a girder consists in bending a piece into a curve, and securing it from springing back by bolts or straps. A girder constructed in this manner is shown by Fig. 71. Smeaton adopted a similar method of strengthening the beam of a steam-engine,† and the addi-

* A girder similar to this is described by Mathurin Jousse, in his 'Art de la Charpenterie.'

† Rees's 'Cyclopædia,' art. Steam-engine, plate i. Girders constructed in this manner have also been proposed by Rondelet, 'L'Art de Bâtir.'

tional stiffness gained by bending beams in this manner is very considerable. The pieces should be well bolted, or strapped, to prevent any sliding of the parts. A beam of this kind might be built of any depth necessary in the erection of buildings, and by breaking the joints it might also be of any length that is likely to be required in the construction of floors.

The thickness of the bent pieces may be about *one-fiftieth* part of the bearing, and any number of them may be used to obtain the required depth, provided the whole depth of the curved pieces do not exceed half the depth of the girder; should they do so, straight pieces must be added to the under-side, so as to make the whole depth of the straight parts exceed that of the curved parts. When pieces cannot be obtained sufficiently long, care should be taken to have no joints near the middle of the length in the lower half of the girder.

Fig. 71 shows a girder for a 40-feet bearing, with the lower half scarfed at *a*, and a plain butt-joint in the curved part at *b*.

FIG. 71.

The rule for finding the scantling of these girders is to multiply $1\frac{1}{2}$ time the area of the floor supported, in feet, by the length of bearing of the girder in feet; the product divided by the square of the depth in inches will be the breadth of the girder in inches.

207. In the construction of floors it would be an advantage to make each girder only half the breadth given by the rule, and to limit the distance apart to 5 feet; to bridge the upper or floor joists over the girders, and notch the ceiling

joists to the under-side of them; and to omit the binding joists. This method would greatly increase the strength and stiffness; and, in point of economy, it is decidedly preferable; only it requires a much greater depth of flooring.

208. As the strain is always greatest at the middle of the length of a girder, it would be well to avoid making mortises there, if possible, either for binding joists or for any other purpose; and the most straight-grained part of the beam should be at the under-side.

Timber girders should not be built into the wall, but an open space left round their ends, either by laying a flat stone over them, or by turning an arch to carry the wall above.

Girders should be laid from 9 to 12 inches into the wall, according to the bearing.

Binding Joists.

209. The depth of a binding joist is generally determined by the depth of the floor, but not always. Rules must therefore be given for at least two cases.

Case 1.—To find the depth of a binding joist, the length and breadth being given.

Rule.—*Divide the square of the length in feet, by the breadth in inches; and the cube root of the quotient multiplied by 3·42 for fir, or by 3·53 for oak, will give the depth in inches.*

210. *Case* 2.—To find the breadth, when the depth and length are given.

Rule.—Divide the square of the length in feet, by the cube of the depth in inches; and multiply the quotient by 40 for fir, or by 44 for oak, which will give the breadth in inches.

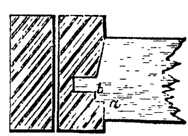
These rules suppose the distance apart to be 6 feet; if it be greater or less than 6 feet, the breadth given by the rule must be increased or diminished in proportion. The breadth

of the binding joists next the wall may be two-thirds of the breadth of the others; but in general they are made the same, or those most defective are selected for that purpose.

211. The binding joists may be from 4 to 6 feet apart, but should not exceed 6 feet; a bearing of about 6 inches on the wall is sufficient.

The manner of framing binding joists into girders is shown by Fig. 72; and in fixing them great care should be taken that both of the bearing parts *a* and *b* should fit the corresponding parts of the mortise. This is the most important part of fitting in a binding joist, yet it is often the least attended to. The tenon should be about one-sixth of the depth, and at one-third of the depth from the lower side.

FIG. 72.



212. Binding joists that have only to carry a ceiling may have their scantlings found by the same rule as for ceiling joists (see Art. 214), except that the quotient must be multiplied by 1·2 instead of 0·64 for fir, and by 1·25 instead of 0·67 for oak joists.

BRIDGING JOISTS.

213. The rule for bridging joists is the same as that for single joisting (see Art. 195). They seldom need be more than 2 inches in thickness, except for ground floors, where they are laid upon sleepers; in which case the depth may be found to a breadth of 2 inches, and an inch may be added to the breadth, on account of the situation; as when proper care is not taken to drain and ventilate the under-side of a ground floor, the joists are subject to very rapid decay. It is a good practice to strew smiths' ashes, or even common ashes, under such floors, to prevent the growth of fungi. The ashes and scoriæ from a foundry, or any ashes that contain much

iron, are the best. Mr. Batson found this an effectual remedy for the dry rot. He filled a space below the floor of 2 feet in depth with anchor-smiths' ashes, and also charred the sleepers.*

CEILING JOISTS.

214. Ceiling joists require to be no thicker than is necessary to nail the laths to; and 2 inches is quite sufficient for that purpose.

To find the depth of a ceiling joist, when the length of bearing and breadth are given.

RULE.—Divide the length in feet by the cube root of the breadth in inches; and multiply the quotient by 0·64 for fir, or by 0·67 for oak, which will give the depth in inches required.

Example.—Let the bearing be 6 feet, and the breadth 2 inches; to find the depth of a ceiling joist of fir.

The cube root of 2 is nearly 1·26; and the length, 6 feet, divided by this number, that is, $\frac{6}{1 \cdot 26} = 4 \cdot 76$; which being multiplied by the decimal 0·64, gives 3 inches, the depth required.

215. If two inches be fixed upon for the breadth, the rule for ceiling joists of fir becomes very easy; for then half the length in feet is the depth in inches: that is, if the length of bearing be 10 feet, the depth of the joist should be 5 inches. The distance apart in the clear is generally from 10 to 12 inches, according to the length of the laths.

It is better to notch ceiling joists to the under-side of the binding joists, and nail them, than to mortise and chase them in; because less labour is required, the binding joists are not weakened, and the ceiling stands better. Oak is not so

* 'Transactions of the Society of Arts,' vol. xii., p. 265.

good a material for ceiling joists as fir, because it is more liable to warp; particularly if not well seasoned.

General Observation respecting Floors.

216. Girders should never be laid over openings, such as doors or windows, if it can be avoided; but when it is absolutely necessary so to lay them, the wall-plates, or templets, must be made strong, and long enough to throw the weight well upon the piers. It is, however, a bad practice to lay girders very obliquely across the rooms; it is sometimes better to use a strong piece as a wall-plate.

In the bearings of floors the caution of Vitruvius must be attended to; that is, when the ends of the joists are supported by external walls of considerable height, the middle part of the joists should never rest upon a partition wall that does not go higher than the floor;* otherwise the unequal settlement of the walls will cause the floor to be out of level, and most likely fracture the cornices.

217. Wall-plates and templets should be made stronger as the span of the girder is increased; the following proportions may serve for general purposes:

	in.		in.
For a 20-feet bearing, wall-plates	$4\frac{1}{2}$	by	3
30 ,, ,, ...	6	,,	4
40 ,, ,, ...	$7\frac{1}{2}$	,,	5

218. Floors when first framed should always be kept about three-fourths of an inch higher in the middle than at the sides of a room; also the ceiling joists should be fixed about three-fourths of an inch in 20 feet higher in the middle than at the sides of the room; as all floors, however well constructed, will settle in some degree.

In laying the flooring, the boards should be made to rise a little under the doorways, in order that the doors may shut

* 'Vitruvius,' lib. vii., cap. 1.

close without dragging; and to assist in making them clear the carpet.

The following observations, from Evelyn's 'Silva,' are worthy of notice: "To prevent all possible accidents, when you lay floors, let the joints be shot, fitted, and tacked down only the first year, nailing them for good and all the next; and by this means they will lie stanch, close, and without shrinking in the least, as if they were all of one piece: and upon this occasion I am to add an observation that may prove of no small use to builders, that if one take up deal boards that may have laid in the floor an hundred years, and shoot them again, they will certainly shrink (*toties quoties*) without the former method." *

Floors constructed with Short Timbers.

219. There are many curious methods of constructing floors with short timbers, which cannot be passed over without notice, and yet are scarcely worthy of it; because they are seldom applied, as long timber may always be had. To those, however, who are more inclined for curious than useful information, the following notices respecting such floors may be acceptable.

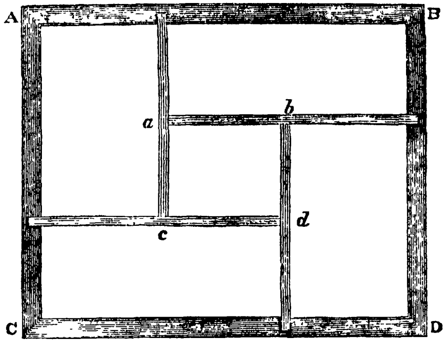
Let A B C D, Fig. 73, represent the plan of a room, and let four joists be mortised and tenoned together at *a*, *b*, *c*, and *d*, in the form shown in the figure; then it is evident that these joists will mutually support one another. Each joist being supported at one end by the wall, and at the other by the middle of the next joist. This is one of the most simple forms, and will sufficiently explain the principle of constructing a floor of timbers shorter than will reach across the room.

The same thing may be done by mortising and tenoning

* Evelyn's 'Silva,' Dr. Hunter's edit., vol. ii., p. 217.

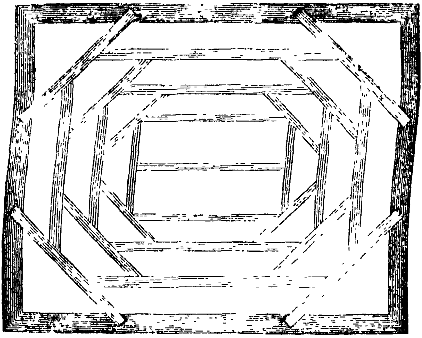
the joists together as in the form represented by Fig. 74; and various other forms will readily suggest themselves, the method being once understood.

FIG. 73.



A design for this kind of floor was given by Serlio;* and the celebrated mathematician, Dr. Wallis, has entered very

FIG. 74.



fully into the investigation of the strength and disposition of these floors, in the first volume of his mathematical works.

* Tutte, 'L'Opera d'Architettura di Serlio da Scamozzi Vineg.,' 1600, lib. i.

The researches of Dr. Wallis have been reprinted in Nicholson's 'Architectural Dictionary,' art. Naked Flooring. The Dutch manner of framing these floors is given in Krafft's 'Recueil de Charpente,' part ii.; and several forms are exhibited in Rondelet's 'L'Art de Bâtir,' tome iv.

220. Perhaps the most singular floor that was ever constructed on a large scale is one executed in Amsterdam, for a room 60 feet square, which has no joists whatever. There are very strong wall-plates on each side of the room, firmly secured with iron straps at the angles, and rebated to receive the flooring. The flooring consists of three thicknesses of $1\frac{1}{2}$-inch boards. The first thickness is laid diagonally across the opening, the ends resting in the rebates of the wall-plates; and rising about $2\frac{1}{2}$ inches higher in the middle than at the sides of the room. The second thickness of boards is also laid diagonally, but the direction is the reverse of the first thickness; and the two thicknesses are well nailed together. The boards of the third thickness are laid parallel to one of the sides of the room, and form the upper side of the floor, being well nailed to the boards below. All the boards are grooved and tongued together, and form a solid floor $4\frac{1}{2}$ inches in thickness.* This example shows how much may be accomplished by a well-disposed bond and firm connection of parts. Such a floor partakes of the nature of a thin plate supported all round the edges; the strength of plates supported in this manner is directly as the square of their thickness, and they are equally capable of supporting a weight in the middle, whatever the extent of bearing may be; but when the load is uniformly distributed, the strength is inversely as the area of the space it covers.†

* Rondelet's 'L'Art de Bâtir.'

† Emerson's 'Mechanics,' 4to, sect. viii., prop. 73, cor. 5.

SECTION IV.

OF THE CONSTRUCTION OF ROOFS.

221. A roof is intended to cover and protect a building from the effects of the weather, and also to bind and give strength and firmness to the fabric. To effect these purposes it should neither be too heavy nor too light, but of a just proportion in all its parts to the magnitude of the building. Mr. Ware observes, "that in practice roofs are generally made too heavy; and that he will do a most acceptable service to his profession who can show how a roof may be constructed with the smallest quantity of timber; by which an unnecessary load will be taken off the walls, and a large and useless expense saved to the owner." *

The timber roofs of our ancestors, in the styles of building called Norman and Gothic, were generally made without horizontal ties at the feet of the rafters, and were intended to be supported by the walls as an arch is supported by its abutments. The heavy walls they were in the habit of erecting in the Norman style, and the skilful disposition of buttresses in the Gothic, rendering ties unnecessary; besides, a tie beam would have been wholly incompatible with their mode of finishing the interior of a building.

Their principles of construction bear a closer analogy to masonry than to modern carpentry. It is true they sometimes erred in placing too great an oblique pressure against the walls, but in general we have more to admire than condemn in those celebrated buildings. The fashion of

* Ware's 'Body of Architecture.'

timber-framed roofs, as applied to great halls, originated about the reign of Edward III. They became common about the year 1400, and spans of considerable extent were roofed in a most judicious manner. The timber roof of the Gothic architects was generally executed in oak, and ornamented with bold and graceful mouldings, having richly carved ornaments at the joinings. The most elaborate specimens are the halls at Christ Church, Oxford, and Hampton Court; that at Trinity College, Cambridge, is somewhat inferior: each of these is 40 feet span.* The span of the roof of Westminster Hall is 66 feet.†

In the old Gothic buildings the roof is always of a high pitch; its outline forms a striking feature, and in general is in graceful proportion to the magnitude of the building: sometimes, however, it presents too extensive a plain surface, of which we have a notable instance in the roof of Westminster Hall. A high roof is in perfect unison with the aspiring and pyramidal character of Gothic architecture; but in the opposite, though not less beautiful style of the Greeks, it becomes a less conspicuous feature; indeed, many of the Grecian buildings were never intended to be roofed at all. Yet when a roof was necessary it was not attempted to be hidden, but constituted one of the most ornamental parts of the structure.

Of timber roofs we have no examples in Grecian buildings; but the beautiful stone roof of the Octagon Tower of Andronicus Cyrrhestes,‡ and that of the Choragic Monument of Lysicrates,§ are sufficient to show that they were more inclined to ornament than to hide this essential part of a building.

222. In carpentry, the term *roof* is applied to the framing of timber which supports the covering of a building. The

* Dallaway's 'Observations on English Architecture,' p. 188.

† Idem, p. 189. ‡ Stewart's 'Athens,' vol. i. § Idem.

pitch of a roof, or the angle which its inclined side forms with the horizon, is varied according to the climate and the nature of the covering. The inhabitants of cold countries make their roofs very high, while those of warm countries, where it seldom rains or snows, make their roofs nearly flat; but the practice even in the same climate has varied considerably. Low roofs require large slates and the utmost care in execution; they are cheaper, since they require timbers of less length and of smaller scantling. Formerly the roofs were made very high, perhaps with the notion that the snow would slide off easier; but where there are parapets a high roof is attended with bad effects, as the snow slips down and stops the gutters, and an overflow of water is the consequence; besides the water in heavy rains descends with such velocity that the pipes cannot convey it away soon enough to prevent the gutters overflowing. In high roofs the action of the wind is one of the most considerable forces they have to sustain, and it is supposed to have been with a view of lessening their height that the Mansard or curb roof was invented. The quantity of room lost by a curb roof, the difficulty of freeing the gutters from snow, and the ungraceful effect of the roof itself, are objections that are not compensated by the small difference of the expense between it and a common roof, especially now that experience has proved that roofs may be made much less in height than our ancestors were in the habit of making them.

223. The height of roofs at the present time is very rarely more than one-third of the span, and should never be less than one-sixth. The usual pitch for slates is when the height equals one-fourth of the span, or when the angle with the horizon is $26\frac{1}{2}$ degrees. Near the sea, or in very exposed situations, the height of the roof should be one-third of the span, for if less the rain and snow will be driven under the slates by the wind.

The pediments of the Greek temples make an angle of from 12 to 16 degrees with the horizon; the latter corresponds nearly with one-seventh of the span. The pediments of the Roman buildings vary from 23 to 24 degrees: 24 degrees is nearly two-ninths of the span.

224. The coverings used for timber roofs are copper, lead, iron, tinned iron, slates of different kinds, tiles, shingles,* and thatch of reeds or straw, the relative degree of slope which each should have being determined by the mode of laying or forming the joints. Taking the angle for slates to be 26½ degrees, the following Table will show the inclination that may be given for other materials, and the weight of each material on a superficial foot of the inclined surface:—

Kind of Covering.	Inclination to the Horizon.	Height of Roofs in parts of Span.	Weight per Super. Foot.		
	° ′		lbs.		lbs.
Tin	5·43	$\frac{1}{20}$	·7	to	1·25
Lead	..	..	5·0	,,	7·0
Zinc	..	..	1·25	,,	2·0
Copper	7·36	$\frac{1}{15}$	·8	,,	1·25
Asphalted felt	18·26	$\frac{1}{6}$	·3	,,	·4
Slates, large	22·0	$\frac{1}{5}$	9·0	,,	11·0
,, ordinary	26·33	$\frac{1}{4}$	5·0	,,	9·0
Thin slabs of stone	..	..	20·0	,,	25·0
Pantiles	..	..	8·0	,,	12·0
Plain tiles	33·40	$\frac{1}{3}$	16·0	,,	20·0
Thatch of straw	45·0	$\frac{1}{2}$	6·0	,,	8·0

225. SNOW just fallen is variously stated by different authorities to weigh from 8 to 14 lbs. per cubic foot. The quantity which falls at a time varies according to climate; in some places it is less than an inch, and in others as much as several feet in thickness. In the climate of New York it

* Shingles are now very little used in this country, though formerly they appear to have been much used. See Neve's 'Builder's Dictionary,' art. Shingle; Britton's 'Archit. Antiq.,' vol. ii., p. 79.

is usual to estimate the depth fallen at $2\frac{1}{2}$ feet. In England it would not be quite so much.*

226. The pressure of an ordinary gale of WIND in England against a vertical surface is from 25 to 35 lbs. on the square foot. Occasionally pressures over 50 lbs. have been known. The highest ever recorded in this country was during a sudden gust on the 27th December, 1868, by Mr. John Hartnup, F.R.S., at the Liverpool Observatory, Birkenhead, which amounted to 80 lbs. on the square foot as registered by Osler's Anemometer.

227. In England it has been usual to calculate on a pressure of 40 lbs. to the square foot for wind, snow, and other occasional forces acting on the inclined surface of a roof. Experience has proved this allowance to be ample, and that it might be reduced when the roof is sheltered from the effects of powerful winds, &c. The instances are very rare where roof timbers have been broken by the wind, but more frequently they have been stripped of their covering by its getting underneath, or from the vacuum caused by its passage over the building.

OF THE FORMS OF ROOFS FOR DIFFERENT SPANS.

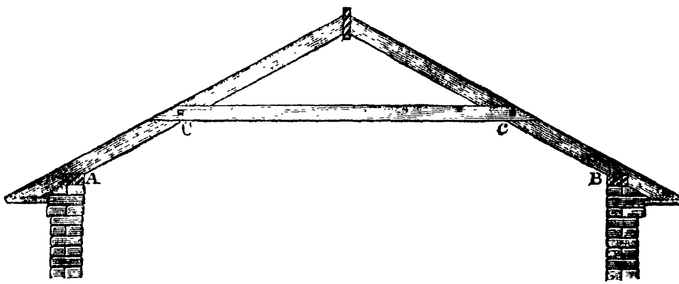
228. The simplest form of roof is that shown in Fig. 75, which is adapted for spans under 20 feet.

It consists of common rafters only, which meet against a ridge-piece at the top, and are held together by a horizontal tie, termed a collar-beam. Additional height is given to the rooms by this form of roof, as the ceiling can be formed by nailing boards or lathing to the under-side of the rafters and collars. The scantling of the rafters can be obtained from Table No. 15 at the end of the volume, the whole length be-

* Hatfield's 'American House Carpenter,' and 'Instructions for taking Meteorological Observations,' Ord. Survey Department.

tween the supports being taken for the bearing. The collars should be of the same scantling as ceiling joists of the same length of bearing, and they should be slightly notched to fit the rafter.

FIG. 75



229. For spans of 20 feet and upwards a truss should be used. The form shown in Plate I., which is called a king-post truss, is adapted for spans of from 20 to 30 feet; within these limits the points of support of the tie-beam and rafters are not too far apart. The scantlings of the timbers are given in Table No. 5 at the end of the volume, according to the span of the roof. The drawing shows a parapet on one side and eaves on the other.

230. The form shown in Plate II., which is called a queen-post trust, is adapted for spans exceeding 30 feet and under 45 feet. Each purlin is supported without inducing cross strains on the principal rafters, and the tie-beam is divided into three comparatively short bearings. The scantlings may be obtained from Table No. 6 at the end of the volume.

The sagging which usually takes place from the shrinking of the heads of the queen posts may be avoided by letting the end of the principal rafter abut against the end of the straining beam S; and notching pieces and bolting them together in pairs at each joint. The side marked D of the

figure is supposed to be done in this manner. This method is further illustrated in Art. 254, and is applicable to other forms of roof.

231. When the span exceeds 45 feet, and is not more than 60 feet, the form of queen-post truss shown in Plate III. is sufficiently strong, and leaves a considerable space in the middle free. For this span the tie-beam will probably require to be scarfed, and as the bearing of that portion of the tie-beam between *a* and *b* is short, the scarf should be made there. The middle part of the tie-beam may be made stronger by bolting the straining sill *s* to it. The scantlings may be obtained from the Table No. 7 at the end of the volume; and the methods of scarfing and forming joints are detailed in a separate section.

232. A truss for a roof from 75 to 90 feet span is shown in Plate IV. In this truss the straining sill *s* should be tabled or keyed, and bolted to the tie-beam in the manner that has already been proposed for increasing the depth of girders (Sect. III.). This truss nearly resembles the roof of the Birmingham Theatre described by Nicholson.*

233. By omitting, or rather reducing, the upper part of the truss in Plate IV. to the same form as that in Plate III., the truss would answer for a bearing of from 60 to 75 feet. The scantlings may be had from the Table No. 8 at the end of the volume.

When the span is so very wide, unless the building be of a proportional height, this form of roof exhibits such an immense amount of plain surface, that the architectural effect of the building is destroyed; besides, it is difficult to light the large space in the roof in any way that would not be open to objection, on account of the external appearance.

234. To avoid a large expanse of roof, the truss may be of

* 'Carpenter's Assistant,' p. 61, Plate lxxiii. 2nd edit.

the form shown in Plate V., which has been taken from *Price's 'British Carpenter.'* A roof of this form is called an *M* roof, and would do for a span of from 55 to 65 feet; but it would be better to adopt the truss represented in Plate IV., making the top flat, and covering it with lead, as the space gained in the roof would amply repay the expense of the lead flat. The scantlings of the M roof may be obtained from the Table No. 9 at the end of the volume.

235. *For spans that exceed 65 feet the truss adopted in the construction of the old Drury Lane Theatre, in 1793, is,* in respect to form, perhaps one of the best of its kind that can be devised where a large open space is required.* Plate VI. shows a roof on the same principle, of which the scantlings may be obtained from the Table No. 10 at the end of the volume. One part of the principal truss is shown with a queen post, the other with suspending pieces, as described in Art. 254 and in the Section on Joints, &c. The middle part of the principal tie-beam is supposed to be built as a girder.

For large spans when a sloping roof is required, the best method is to use small king-post trusses, as in Plate VI., and to support them on a wrought-iron girder, which for a span of 80 feet need seldom be more than 6 feet deep, instead of 18 feet as the truss in Plate VI. Sometimes, however, deep wooden trusses may be used as partitions between the rooms, in which case they are not so objectionable as they otherwise would be.

236. There is much difficulty in executing a roof when the joints are numerous and the timbers of large dimensions; as the shrinkage of the king or queen posts often produces considerable derangements in the truss. It is obvious, that to make principal rafters in a continued series of pieces abutting end to end against one another would remedy these

* A description of the roof of Drury Lane Theatre is given in Nicholson's 'Carpenter's Assistant,' p. 60, Plate lxxi.

defects. These pieces would then form a kind of curve, which might be made regular, or left with projecting angles, as shown by Fig. 76. They could either be bolted or mortised and put together with wooden keys, as represented in Fig. 77. The length of the pieces would be determined by the form of the curve; crooked timber where it can be procured would be preferable for the ribs, as the joints should be as *few as possible, and they should be crossed like the joints in stone-work.*

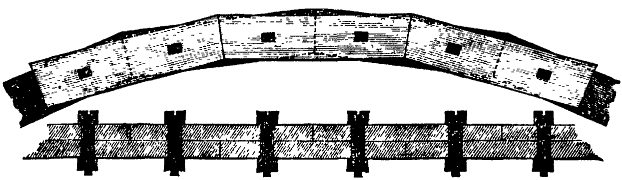


FIG. 77.

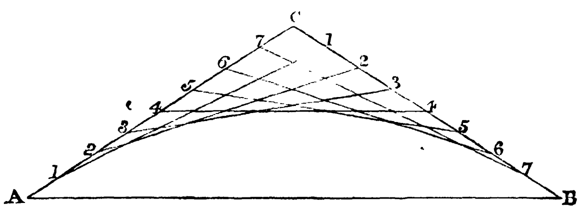
Plate VII., Fig. 1, shows a roof constructed in this manner. Each of the supports for the tie-beam marked S, S, &c., consists of two pieces, one put on each side of the rib, and notched both to the rib and to the tie-beam. The pieces are bolted together, as shown by a section to a larger scale, through one of these pairs of suspending pieces, in Fig. 2. This mode of construction admits of a much firmer connection with the tie-beam than is obtained by the ordinary mode, and the number of suspending pieces may be increased at pleasure. The best situation for the suspending pieces is at the joints of the curved rib.

The weight of the roof being very nearly uniformly distributed, the form of the curved rib should be a parabola (see Sect. I., Art. 64); and as this curve is easily described with sufficient accuracy for the purpose, it is best to adopt it, because, in that case, the strain from the weight of the roof and ceiling will have no tendency whatever to derange the form

of the rib; and its depth will always be sufficient to withstand any partial force to which a roof is likely to be exposed. Consequently, when the rib is of a parabolic form, diagonal braces will not be required; nevertheless they may be added if thought necessary, as shown by the lines in the figure, particularly as they will increase the strength to resist partial strains.

To construct the parabola, let A B, Fig. 78, be drawn for *the upper side of the tie-beam, and A C, C B, for the under side of the common or small rafters. Then divide A C and C B each into the same number of equal parts (an even number is to be preferred), and join the points* 1 and 1, 2 and 2, &c.; then the curve formed by these intersecting lines will be the parabola required.

FIG. 78.



But it will be found that this curve scarcely differs from a circular arc that rises half the height of the roof; therefore, either may be used.

If a lantern or other structure is to be raised on the top, a hyperbolic curve should be adopted; which admits of a considerable increase of pressure at the crown.

The scantlings of the curved ribs are given in Table No. 12 at the end of the volume. The tie-beam will require to be scarfed for large spans, and would be best made in two thicknesses, and joined so that the scarfs should not be opposite one another.

237. Roofs of less span and rise might be constructed in a similar manner, at a comparatively small expense. But in these, instead of forming the rib of short pieces, it might be bent by a method somewhat similar to that used for bending ship-timber.

If the depth of a piece of timber does not exceed about a *hundred and twentieth part of its length*, it may be bent into a curve that will rise about *one-eighth* of the span without impairing its elastic force. And if two such pieces be laid one *upon the other, and then bent together by means of a rope fixed at the ends, they may be easily bent to the form of the* required curve, by twisting the rope as a stone-sawyer tightens his saw, or as a common bow-saw is tightened. The pieces may then be bolted together; and if this operation be performed in a workman-like manner, the pieces will spring very little when the rope is gently slacked; and it is advisable to do it gradually, that the parts may take their proper bearing without crippling.

Otherwise, a piece of about one-sixtieth part of the span in thickness may be sawn along the middle of its depth, with a thin saw, from each end towards the middle of the length, leaving a part of about 8 feet in the middle of the length uncut. The pieces may then be bent to the proper curve, and bolted as before.

In either case the rise of the ribs should be half the height of the roof; and they should be bent about one-fourth more, to allow for the springing back when the rope is taken off. A roof of this kind for a 30-feet span is shown by Plate VIII. The suspending pieces are notched on each side, in pairs, and bolted or strapped together, as shown by Fig. 2, Plate VII.

The advantages of this roof consist in the small number of joints in the truss, in being able to support the tie-beam at any number of points, in admitting of a firm and simple connection with the tie-beam, and in avoiding the ill effects

attending the shrinking of king or queen posts. The scantlings are given in Table No. 11 at the end of the volume.

238. In the construction of modern roofs a continued tie at the foot of the rafters or some other means of relieving the thrust is almost always necessary, though sometimes it has been omitted, for in general the lightness of the walls renders them incapable of sustaining much lateral pressure; and this pressure is entirely removed by a tie-beam or an iron tie-rod.

As leaving out the tie-beam gains only a very small space in height, which might generally be obtained without injury to the external appearance of the building, by raising the walls a little higher, we will endeavour to show the defects of roofs without rods or tie-beams.

Referring to the roof described in Art. 228, the whole weight of such a roof is sustained by the parts of the rafters A C and B *c* (Fig. 75), and when the roof has the weight of the covering upon it, it will settle in proportion to this weight, in consequence of the lower parts of the rafters bending at C *c*, which will tend to press out the walls. The reader will *readily see that a pressure against the walls in this mode of construction cannot be altogether avoided, though it may be* lessened, by making the rafters very strong at the lower part. Failures have often been observed from adopting this form of roof, which should never be used except for very short spans, and then the precaution should be taken not to cut into the rafters at the points C *c*, where the ends of the collar-beam are fixed, but simply to nail them. The nails should be driven near to the back edges of the rafters, which being in compression from the cross strains are not weakened.

239. In wider spans another mode of construction has been employed, which, though better, is not a good one, from the powerful strains that are caused by the oblique disposition of the beams. To show the nature of these strains Plate IX. is

taken from Price's work,* where much is said in praise of it, Price probably not being capable of investigating its construction according to the principles of mechanics. The essential parts of this roof are contained in Fig. 9, page 12; and by comparing the strains produced by the weight in that figure with the strains when C A is in a horizontal position, it will be found the strains are more than doubled by the oblique position of C A. Returning again to the section of the roof in Plate IX. Let the vertical line *a* E be drawn, and let *a b* upon this line represent the weight of half the roof; also draw *c b* parallel to A C, and *c a* parallel to A D. Then the weight and pressures will be measured by *a b*, *b c*, and *a c*. But if there had been a tie-beam A B, the pressures produced by the same weight would have been only *b d* and *a d*; hence it appears that they are nearly doubled, while the space gained in the middle in height amounts only to about one-ninth of the span. To gain this small advantage, we encounter the difficulty of making a firm connection of the ties at C, with the certainty of a considerable degree of settlement *from the number of the joints and the magnitude of the strains. It also must be remembered, that the same degree of settlement will produce a greater effect in thrusting out* the walls in proportion as C E is greater. Having thus pointed out the defects of this kind of roof, we shall leave the reader to judge for himself as to the propriety of adopting it.

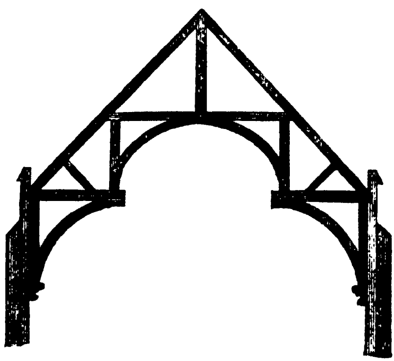
240. The centre aisle of churches being often higher than the sides, the same effect as when the tie continues through may be produced by connecting the lower beams to the upper one by means of braces, so that the whole may be as a single beam. To illustrate this principle take the roof in Plate X., which is for a church similar to St. Martin's, in London.

* 'British Carpenter,' Plate K, Fig. L.

Here the lower ties, B, B′, are so connected to the principal tie-beam A A′, by means of the braces *b*, *b*′, that the foot of the principal rafters P, P′, cannot spread without stretching A A′. The iron rods, *a*, *a*′, perform the office of king posts to the ties B B′, and are better than timber, because the shrinkage of timber ones would be particularly objectionable in that situation. The oblique positions of *d d*′ will render them effectual in opposing the spread of the rafters.

Fig. 79 is a sketch of the roof of Westminster School, from Smith's 'Specimens of Ancient Carpentry.'* It shows the

FIG. 79.



form most usual for Gothic halls, which differ more in the ornaments and tracery than in the essential parts of the framing. The timbers are so disposed as to throw the pressures a considerable way down the walls, and at the same time in nearly a vertical direction. Indeed, considering the effect that was intended to be produced, the arrangement of the parts is worthy of much praise.

The roof over the nave of Starston Church, in Norfolk,

* Plate VIII. Smith's specimens would have been valuable if they had been accompanied with dimensions and a short description of each.

shown by Plate XI., taken from Brandon's 'Open Timber Roofs of the Middle Ages,' is another specimen of the skill displayed by the old Gothic architects, who, unlike some of their modern imitators, managed to combine science with art.

The method in which the arched braces are united at the apex of the roof is very ingenious. The principals are framed into a strut about 9 inches square which hangs down 2 feet below them. The four sides of this strut are mortised to receive the ends of the braces which are let into them and fastened with wooden pins. The under-side of these struts is finished with a boldly-carved flower. The cornice is framed in lengths between the wall-plates of the principal trusses, and the struts and wall-beams of the common rafters are tenoned into it and secured with wooden pins. The span of the roof is nearly 22 feet, and the scantlings of the timbers as follows:—

	in.		in.
Principal rafters	10	×	9
Common ,, ...	6	×	4
Wall-pieces	10	×	$7\frac{1}{2}$
Purlins	$6\frac{1}{2}$	×	$5\frac{1}{2}$
Cornice	11	×	10

Plate XII. is a sketch of a Gothic roof from Demanet's 'Cours de Construction.' Its simplicity is the chief recommendation. It has the disadvantage, however, which is common to most Gothic roofs, of causing a great waste of timber to produce the form necessary for strength and lightness.

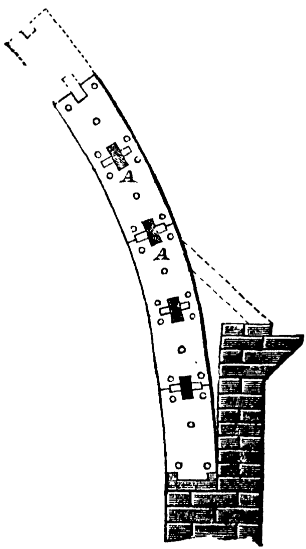
Plates XIII. and XIV., taken from the 'Builder' journal of 1860 and 1867, are examples of modern Gothic roofs with hammer-beams, the former over St. Paul's Church, Haggerston, and the latter over the Church Institute at Leeds.

241. A most ingenious method of forming curved ribs of short pieces of timber was introduced by the celebrated archi-

tect Philibert de Lorme, and described by him in a work published in 1561.* It consisted in placing two thicknesses of planks or flitches, in pieces about 4 feet long, so that the joints formed by the pieces on one side came in the middle of the length of those on the other side. The width of the planks for a span of 25 feet was about 8 inches, and the thickness of each plank was about 1 inch. For spans of 100 feet he made the ribs 13 inches wide, and the pieces of which they were formed 3 inches thick.

The ribs were placed about 2 feet apart and sprung from plates laid upon the walls (Fig. 80). The plate was usually mortised to receive the end of the rib, which had a short tenon formed on it.

Fig. 80.



The several ribs of which the roof was composed were held in their places by longitudinal ties, about 1 to $1\frac{1}{2}$ inch thick by 4 inches wide, passing through mortises cut in the planks. These ties were fixed at intervals of 2 feet, and were pinned on each side of the ribs with keys 1 inch by $1\frac{1}{2}$ inch, as shown by Fig. 80. The space between the mortises was a little less than the thickness of the rib, in order that when the keys were driven home they might press tightly against the sides of the ribs. Some-

* Emy, 'Traité de Charpenterie.'

times, to save labour, the space between the mortises was cut away.

Several roofs have been constructed on this principle, one of them covered the stable of the Tuileries at Paris, and remained perfectly sound and secure for 234 years, until removed to admit of improvements in the palace.

These ribs are nearly as strong as a solid one of the same depth and of a breadth less by the thickness of one flitch.

A roof, Plate XV., on the principle of De Lorme, but with the addition of rafters above the ribs, was designed by Colonel Emy in 1803 for the Artillery and Engineer Riding School at Metz. The ribs, which were placed 2 feet apart, were composed of three thicknesses of $1\frac{1}{4}$-inch planks 10 inches wide.

The span of the roof as executed was only 34 feet, though originally designed for a span of 46 feet; but a considerable time had elapsed between the dates of the design and the execution of the work, resulting in a change of site, which proved to be more contracted than the former one.*

The roof adopted for the annexes of the Exhibition Building of 1862 was after the same principle, though much inferior to its prototype, as proved by the symptoms of weakness which it exhibited soon after its erection.

242. Plate XVI. shows a roof with a laminated arched rib, erected at Marac, near Bayonne, by Colonel Emy in 1826, and claimed by him as a new invention, which he had used in the design for the roof of a Riding School at Libourne in 1819. It had been, however, suggested for application to bridges some years before by M. de Saint-Phar, though not carried into execution. The system was probably well known from the model which was to be seen at the School for Bridges and Roads in France.

* Emy, 'Traité de Charpenterie.'

The rib shown in Plate XVI. consisted of a series of thin planks or lamina, each about $2\frac{1}{8}$ inches thick and $5\frac{1}{8}$ inches wide, in lengths of about 40 feet, placed one over the other, and bent into an arc of $65\frac{1}{2}$ feet span. The lamina were then bolted together with iron bolts $\frac{11}{16}$-inch diameter, at intervals of about $2\frac{1}{2}$ feet, which retained them in the curved form to which they had been bent previously. So slight was the tendency to change from this form, that the rib spread out only about 6 inches on being relieved from the pressure by which it was bent.

Between every pair of bolts was an iron strap which embraced the rib on all sides and effectually prevented any separation of the lamina. The bolts were omitted at the crown to about 6 feet on each side, but the straps were used all the way round. The number of lamina varied, the least number being five and the greatest eight, which arose from supplementary ones being required at the haunches to resist the strains caused by the weight of the roof.

The manner in which the rafters and other timbers were connected to the rib, almost effectually prevented any outward thrust on the walls.

These ribs or principals were placed about 9 feet 10 inches apart, and were connected with each other by horizontal pieces at the haunches, and were notched to the radials which intersected the feet of the rafters, and again at the crown by similar horizontal pieces, which were fixed to the vertical timbers connecting the apex of the roof with the crown of the arched rib.

According to the experiments of M. Ardant, ribs of this description without external or internal bracing, are weaker than solid ones of the same dimensions, nearly in the ratio of unity to the number of layers into which they are divided.

Ample details of these roofs will be found in the 'Traité de Charpenterie,' published by Colonel Emy in 1841.

243. Plate XVII. shows another roof taken from the work of Colonel Emy, for which he was indebted to Kraft, who relates that it was designed by M. Mandar for a provision store at Helder, in Holland. The rafters were supported by a solid arched rib formed in five lengths, connected by scarfs. The length of the store for which this roof was designed is nearly 320 feet, and the width 64 feet. The ribs were spaced 16 feet apart from centre to centre, and between each pair were six rafters, which supported the roof. The feet of the ribs sprung from plates of timber secured to the floor-beam, causing the latter to act as a tie to the roof.

The floor-beams were supported by posts, which were indispensable in consequence of the great span, *viz.* 64 feet. Indeed the whole arrangement seems well adapted to the purpose for which it was intended. Of course an architect designing a roof on this principle at the present time would avail himself of the use of iron to a greater extent than appears in this design of M. Mandar.

244. In modern roofs the use of wrought iron in combination with wood has been more extensive than formerly. Instead of being confined to straps and screw bolts, it is now used for king and queen bolts, ties, and struts, and sometimes for principal rafters and purlins. But for common rafters, which require to be battened or boarded over, and for tie-beams, which have to carry a ceiling, wood has the advantage from the facility with which other timbers can be fixed to it.

When the roof is not required to support a ceiling, an iron tie-rod is preferable to a wooden beam.

For purlins, principal rafters, and struts, rolled iron can now be procured of almost any shape or size likely to be required.

As an inquiry into the principle of constructing roofs of iron would be out of place in a work on Carpentry, we shall

confine our illustrations to those cases where the use of iron as forming a part of the truss is limited to ties and struts.

The simplest application of wrought iron is in such cases as shown by Plate XVIII., which is the same as the ordinary queen-post truss on Plate II., except that iron rods are substituted for the queen posts. The heads of these rods are fixed to the iron sockets, which take the ends of the straining beam and principal rafters. The lower ends pass through the cast-iron shoes, which receive the feet of the struts that support the principal rafters, and are continued through the tie-beam and secured by a nut, which enables the bolts to be screwed up tight.

Plate XIX., Fig. 1, shows a form of roof suitable for a shed, where as much clear space as possible in height is required. The strain on the rafters, where connected by the collar-beam, is relieved by iron tie-rods, which are suspended at a considerable height by the king bolt, to which they are secured by a screwed end and nut. The lower ends of the ties are fixed to the cast-iron boxes (Fig. 2), by which the rafters are attached to the longitudinal bearers over the columns which support the structure.

A better arrangement, if it did not interfere with the space in the roof, would be to keep the tie-rods horizontal, or nearly so, and to continue the king bolt down to it, as there will always be a tendency to thrust out the sides when the ties are so much inclined as they are shown in Plate XIX.

Fig. 3 shows the arrangement by which the rafters and ridge-pieces are secured in a cast-iron socket.

A better arrangement for an open roof, with iron ties and struts, is shown by Plate XX. The tie-rods are made to pass through the feet of the rafters, and are secured to a continuous plate of wood, which rests on the walls. The struts shown in the drawing are supposed to be cast iron; but a

piece of wrought T or angle iron would be preferable, and could be as readily secured to the ties and rafters.

A very superior arrangement for a roof, which has to carry a ceiling, is shown by Plate XXI. In consequence of the suspension of the tie-beam, at so many points, the timber is not required to be of so large a scantling as in the ordinary queen-post truss.

In long spans, owing to the length required for some of the struts, wrought iron should be used in preference to wood.

There is no reason why the principle on which girders are used in the construction of bridges should not be applied to roofs.

Plates XXII. and XXIII. show a design by Mr. Pennethorne for the roof of the Lecture Room at the London University.

The purlins were also trussed frames. Indeed, the architect appears to have availed himself of the principles of practical science in a manner that indicates a tendency to improvement in this class of structure.

245. Cast iron has also been extensively used in combination with wrought iron and wood in the construction of roofs, but its adoption is not to be recommended where there is a liability to sudden strains, particularly cross strains.

Plate XXIV. shows a judicious combination of cast iron, in the form of struts, with wrought-iron ties and wood-rafters. For shoes and sockets cast iron is of course unobjectionable, and has been much used in securing the ends of the timber framing: the ease with which it can be moulded to any shape renders it for this purpose a valuable auxiliary in the practice of Carpentry.

246. Plates XXV. and XXVI. are designs taken from Emy's and Demanet's works before mentioned.* The first is particularly adapted for a shipbuilder's shed, and the

* 'Traité de Charpenterie,' and 'Cours de Construction.'

second might also be used for the same purpose or to cover a wharf, and for a variety of other purposes. It has been used for covering some of the locomotive sheds on the Paris and Versailles Railway.

247. Plate XXVII. shows a design for a curb-roof, which the taste of the present period has rendered common in England. Roofs constructed on this principle, being so much exposed to the effects of the wind, require to be well braced, and if the truss can also be used as a partition, as shown, it will add considerably to the stiffness.

The drawing shows the floor-beam of the truss, as unsupported throughout its whole length. Usually there are division walls to the rooms underneath, on which it may be allowed to rest, if they are sufficiently strong to carry the weight.

248. We shall conclude our description of roof trusses with one that was executed more than 400 years ago for the Basilica of St. Paul's at Rome (Plate XXVIII., Fig. 1). The truss is double, that is, consisting of two similar frames placed 14·9 inches apart, and one of these double trusses is placed at about every 10½ feet apart.

The principal rafters abut against a short king post *k*. Between the trusses is placed a piece of timber *s*. Sustained by a strong key of wood passing through it, and through the short king posts, this piece sustains the tie-beams by means of another strong key at *a*. The tie-beams are in two lengths, and scarfed together, as shown by Fig. 2. The scarf is held by three iron straps.

SCANTLINGS OF THE TIMBERS.

	in.		in.
Tie-beams, *t*	22·5	by	14·9
Principal rafters, *p* ..	21·75	by	14·9
Auxiliary rafters, *b* ..	13·8	by	13·3
Straining beam, C ..	14·9	by	12·8
Purlins, *d*	8·5	square, and 5 ft. 7 in. apart.	
Common rafters	5·3	by	4·25, and 8·5 in. apart.

The roof is made of fir, and the span is 78·4 feet. The common rafters are covered with strong tiles, about 12 inches by 7 inches, forming a kind of pavement set with mortar in the joints. On this pavement plain tiles, with ledges, are laid, and the joints covered with crooked tiles, as represented by Fig. 3. From this description some notion may be formed of the load supported by the roof.*

This roof is simple and strong, and the method of sustaining the middle of the tie-beam is ingenious: the covering though heavy is well calculated to exclude the heat and to preserve a uniform temperature within the building, which is a great advantage in a warm climate.

Note.—In former editions of this work was shown a design for a roof of 235 feet span, copied from Kraft's 'Recueil de Charpente,' and stated to have been used for the Riding House at Moscow, built in 1790. As no such roof was executed, according to the statement of M. de Betancourt, Chief Director of Public Roads in Russia, that actually used being of a different design, this roof of Kraft's has been omitted from the present edition.—Ed.

On Proportioning the Parts of a Roof.

249. The proportions to be given to the timbers of a roof depend so much on the design of the framing that it would be difficult to furnish rules to apply in all cases. Therefore those cases only are taken which are most frequently to be met with in practice. But with the aid of the principles already given in this work, and of such data as practice alone can supply, the carpenter will find no difficulty in ascertaining the proportions to be adopted in other designs.

In roofs as in floors the constant number in the rules has been derived from a comparison of examples already executed, and which have been known to stand.

* Rondelet, 'L'Art de Bâtir.' The roof of the church of Santa Maria Maggiore at Rome is similar, the span of which is nearly 56 feet, and the tie-beams 15 inches by 10½ inches. See Kraft's 'Recueil de Charpente.'

Of King Posts (*sometimes called Crown Posts*).

250. The king post is intended to support the ceiling, and also by means of the braces to support a part of the weight of the roof. It is marked K in the roof on Plates I., IV., and VI.

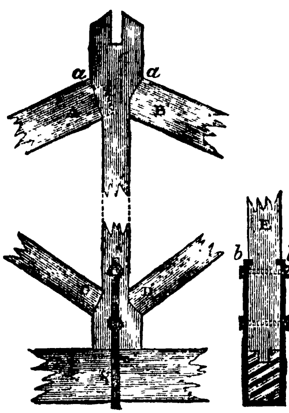
The weight suspended by the king post will be proportional to the span of the roof; therefore to find the scantling,

Rule.—Multiply the length of the post in feet, by the span in feet, and the product by the decimal 0·12 for fir, or by 0·13 for oak, which will give the area of the king post in inches. This area divided by the breadth will give the thickness, or by the thickness will give the breadth.

When a wrought-iron rod is to be used instead of the wooden king post its diameter may be found as follows:—

E.—Multiply the square root of the span of the roof in feet by 0·2, and the result will be the diameter of the king bolt in inches.

Fig. 81



251. The common method of framing the principal rafters to the king post is shown by Fig. 81, but should the roof settle, the whole bearing will be on the upper angles of the joints, as at *a*, and the sharp angles will indent the king post, or will themselves become bruised, and consequently cause the settlement to increase. As all roofs may be expected to settle more or less, the carpenter should endeavour, when fitting the timbers, to make them bear slightly on the opposite corner.

Queen Posts and Suspending Pieces.

252. Queen posts and suspending pieces are strained in a similar manner to king posts, but the load upon them is proportional only to that part of the length of the tie-beam sustained by each suspending piece or queen post. The part suspended by each queen post is generally half the span.

Rule.—Multiply the length in feet, of the queen post or suspending piece, by that part of the length of the tie-beam it supports, also in feet. This product multiplied by the decimal $0 \cdot 27$ for fir, or by $0 \cdot 32$ for oak, will give the area of the post in inches; and this area divided by the thickness will give the breadth.

Example.—In the roof (Plate II.) each queen post, Q, supports one-third of the tie-beam, or $13 \cdot 3$ feet of it, and the length of the queen post is 6 feet; therefore $13 \cdot 3 \times 6 \times 0 \cdot 27 = 21 \cdot 546$, the area in the shaft in inches. If the thickness of the truss be 6 inches, then $\frac{21 \cdot 546}{6} = 3 \cdot 6$ nearly, and the queen post should be 6 inches by $3 \cdot 6$ inches. It is taken 6 by 4 in the Table No. 6.

These rules give the scantling in the smallest part of the pieces, and in order to avoid the bad effects arising from the shrinking of either king or queen posts, the heads should be kept as small as possible, and the timber must be well seasoned. Hard oak makes the best, because it will be least compressed by the ends of the principal rafters.

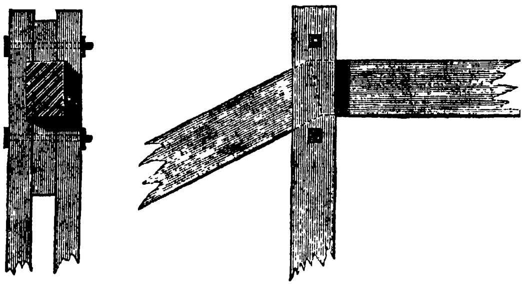
253. For a cast-iron king or queen post the breadth should be about one-fourth of an oak one. Cast iron is rarely used for this purpose, nor is it to be recommended.

To find the diameter of a wrought-iron queen bolt.

Rule.—Multiply the square root of the length in feet of that portion of the tie-beam suspended by the queen bolt by the decimal $0 \cdot 29$, and the result will be the diameter in inches.

254. Instead of the ordinary method of framing the king post between the ends of the rafters (Fig. 81), or the queen post between the rafter and straining beam, it is better to let the rafters, &c., abut one against the other end to end, and to notch a piece on each side as shown in Fig. 82, and to bolt

FIG. 82.



through them. These pieces we call *suspending pieces* instead of "posts," the latter being the more common term, but one very likely to give a false notion of the office which these timbers perform.

TIE-BEAMS.

255. A tie-beam is affected by two strains, one in the direction of the length from the thrust of the principal rafters, and the other, which is a cross strain, from the weight of the ceiling. In estimating the strength, the thrust of the rafters need not be considered, because the beam is always abundantly strong to resist this strain; and when a beam is strained in the direction of the length, it rather increases the strength to resist a cross strain. Therefore the pressure or the weight supported by the tie-beam will be proportional to the length of the longest part of it that is unsupported. But there are

two cases—one where the weight is merely that of a ceiling; the other where there are rooms in the roof.

Case 1.—To find the scantling of a tie-beam that has only to support a ceiling.

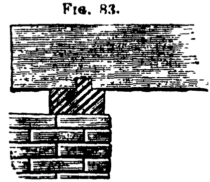
Rule.—*Divide the length of the longest unsupported part by the cube root of the breadth; and the quotient multiplied by* 1·47 *will be the depth required for fir, in inches*; or multiply by 1·52, which will give the depth for oak, in inches.

256. *Case* 2.—In the case where there are rooms above the tie-beam, the rule is the same as that for girders (see Sect. III., Arts. 196 and 197).

Example to Case 1.—The length of the longest unsupported part of the tie-beam in the roof (Plate V.) is 17 feet; and let the thickness of the truss be 9 inches. Then the cube root of 9 is 2·08 very nearly; therefore $\frac{17 \times 1 \cdot 47}{2 \cdot 08} = 12$ inches, the depth required.

257. Tie-beams are often unnecessarily cut to pieces with mortises where the king or queen posts join them, it is much better to make the tenons to the lower end of these posts very short, and to support the beam by means of straps. The best method of cocking or cogging the tie-beam upon the wall plate is shown by Fig. 83.

Fig. 83.



Sometimes blocks are placed under the ends of tie-beams, for the purpose of adding to the security of the roof in case they should decay. The roof of the Basilica of St. Paul's (Plate XXVIII.) has blocks of this kind. Several modern roofs have also been done in this manner, but as these blocks are as liable to decay as the tie-beam itself they cannot be of much use. And by adding to the depth of timber at the points of support, the settlement from shrinkage will be increased. Also, whether the blocks be firmly connected to

the tie-beam or not, by raising the middle part of the tie-beam above the real points of support, a lateral pressure equivalent to that of a cambered beam will be exerted against the walls.

If the ends of the tie-beams be left with a perfectly free space round them, so that there would be nothing to retain any moisture in contact with them, there would be little to apprehend from decay. And if a further security should be thought necessary, cast-iron plates might be used instead of wooden blocks.

It is a common practice in framing roofs to force the tie-beam to a certain degree of camber, which appears to have been introduced under the idea that a cambered beam partakes of the nature of an arch; this, as has been justly observed by a late writer,* is one of the fallacies which it is the business of the mathematical theory of carpentry to dispel. It is obvious that when a cambered beam settles it has a tendency to thrust out the walls instead of being a bond to tie them together. The Gothic builders sometimes laid naturally crooked timbers with the round side upwards for tie-beams; but then their walls were capable of supporting a considerable lateral pressure. In some of the tie-beams of Durham Cathedral this curvature is very considerable; but modern walls are designed on different principles, and require all the assistance that can be given to them by the roof, instead of being sufficient of themselves to withstand the thrust of a cambered beam. Where there are ceiling joists it is easy to keep them a little higher in the middle of a ceiling, at the rate of about an inch in 20 feet, which prevents any settling that may take place, from offending "the eye of the beholder;" and consequently accomplishes all that Mr. Price and others propose to do by cambering the tie-beam.

258. When there is no ceiling nor floor in the roof to

* 'Encyclopædia Britannica,' art. Carpentry.

support, and the walls are not sufficiently thick to resist the thrust of the rafters, a wrought-iron tie-rod may be used instead of the wooden tie-beam.

The thickness of the rod will depend on the design of the roof, and even in the same design, on the number of queen bolts and struts; but by finding the strains according to the principles given in Section I. of this work, and by allowing *one square* inch for every 5 tons of direct strain, the sectional area of the tie-rod can easily be found for any particular case.

Principal Rafters.

259. In estimating the strength of principal rafters, they are assumed to be supported by struts, either at or very near to all the points where the purlins rest. The pressure on a principal rafter is in the direction of its length, and is in proportion to the magnitude of the roof; but this pressure does not bear the same proportion to the weight when there is a king post, as when there are queen posts; therefore, the same constant number will not answer for both cases.

Case 1.—To find the scantling of the principal rafter when there is a king post in the middle.

Rule.—Multiply the square of the length of the rafter in feet, by the span in feet; and divide the product by the cube of the thickness in inches. For fir, multiply the quotient by ·096, which will give the depth in inches.

260. *Case* 2.—To find the scantling of a principal rafter when there are two queen posts.

Rule.—Multiply the square of the length of the rafter in feet, by the span in feet; and divide the product by the cube of the thickness in inches. For fir, multiply the quotient by 0·155, which will give the depth in inches.*

The thickness is generally the same as the king or queen posts and tie-beam.

* For other forms of truss the stress on the rafters should be obtained by the graphic, or other methods, and the scantlings calculated as for pillars of wood.

Example.—The length of the principal rafter P, in Plate II. is $14\frac{1}{2}$ feet, and the span is 40 feet, the thickness of the truss 6 inches. The square of the length is 210·25, and the cube of the thickness 216. Therefore $\frac{210 \cdot 25 \times 40 \times 0 \cdot 155}{216} =$ 6 inches nearly; that is, the principal rafters should be 6 inches by 6 inches

Straining Beams.

261. A straining beam is the horizontal piece between the heads of the queen posts, and is marked S in the roof (Plate II.).

In order that this beam may be of the best form for strength, its depth should be to its thickness as 10 is to 7.

Rule.—Multiply the square root of the span in feet, by the length of the straining beam in feet, and extract the square root of the product. Multiply this root by 0·9 for fir, which will give the depth in inches. To find the thickness multiply the depth by the decimal 0 7.

Struts and Braces.

262. The part of the roof supported by a strut or brace is easily ascertained from the design, but the effect of the load must depend on the position of the brace; when it is square from the back of the rafter, the strain upon it will be the least; and when it has the same inclination as the roof, the same strain will be thrown on the lower part of the principal rafter as borne by the strut. But as the degree of obliqueness does not vary much, no attempt will be made to include its effect in the rule for scantling.

Rule.—Multiply the square root of the length of the rafter supported in feet by the length of the brace or strut in feet; and the square root of the product multiplied by 0·8 for fir

will give the depth in inches; and the depth multiplied by the decimal 0·6 will give the breadth in inches.

Example.—In the roof (Plate II.) the part supported by the brace or strut B is equal to half the length of the principal rafter, or 7 feet; and the length of the brace is 6 feet. Therefore $(7^{\frac{1}{2}} \times 6)^{\frac{1}{2}} \times 0 \cdot 8 = (2 \cdot 646 \times 6)^{\frac{1}{2}} \times 0 \cdot 8 = 3 \cdot 985 \times 0 \cdot 8 = 3 \cdot 188$, the breadth; and $3 \cdot 188 \times 0 \cdot 6 = 1 \cdot 9128$, the depth; or $3\frac{1}{4}$ by 2 nearly.

If a piece intended for a brace, a principal rafter, or a straining beam, be crooked, the round side should be placed upwards.

263. Rules have now been laid down for the principal parts of a truss, but in so doing no account has been taken of the weights of different kinds of roofing, nor the different degrees of inclination, lest the rules should become too complicated. For general reference the Tables of Scantlings at the end of the volume will be found useful, and with the assistance of a table of squares and cubes, or a table of logarithms, all the rules may be expeditiously worked out.

Purlins.

264. The stress upon purlins is proportional to their distance apart; and, the weight being uniformly diffused, the stiffness is reciprocally as the cube of the length.

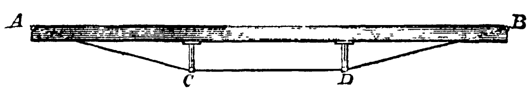
Rule.—Multiply the cube of the length of the purlin in feet by the distance they are apart in feet, and the fourth root of the product for fir will give the depth in inches; or multiplied by 1·04 will give the depth for oak, and the depth multiplied by the decimal 0·6 will give the breadth. See Table 14 at the end of the volume.

Purlins should always be notched upon the principal rafters, and should be put on in as long lengths as they can be obtained, so that they may have a continuous bearing over

the points of support, as the strength is increased by this means. The old method of framing the purlins into the principal rafters not only weakens the purlins, but also wounds the principal rafter, which in consequence should be increased in scantling.

There is no part of a roof so liable to fail as the purlins; in many cases they have been known to sink so much as to deform the external appearance of the roof. Weak purlins might be strengthened by bracing, a practice that was once very common among the builders in this country, and one that might always be adopted with advantage. When the roof trusses are large it is desirable to place them at a greater distance apart than when they are small, in order to save the expense and lessen the weight upon the walls. In such cases it is essential that the purlins should be trussed. A simple method of trussing beams of timber with wrought-iron rods is shown by Fig. 84. It has been frequently adopted in

FIG. 84.



stagings, and for strengthening the beams of the travelling platforms used in the erection of large works. For purlins the depth of the truss might be taken at $\frac{1}{12}$th of the span, and the distance apart of the stays C and D at $\frac{1}{3}$rd of the span. With these proportions the following rules will give the diameter of the wrought-iron rods.

For the horizontal part C D

RULE.—Multiply the square-root of the weight in cwts. supported by the purlin, including one-half of its own weight, by the decimal 0·13, and the product will be the diameter of the rod in inches.

For the parts A C and D B.

RULE.—Multiply the square root of the gross weight, as in the last rule, by decimal 0·15.

When there is not sufficient thickness in the purlin to admit of the rods passing through its substance at the ends, the parts A C and D B might be formed of two rods or flat bars, which can be fastened on each side of the timber and bolted to a cross-plate. In this case the sum of the areas of a cross section of the two rods or bars in inches should equal about $\frac{1}{50}$th of the gross weight on the purlin in cwts. The cross section of a purlin trussed in this manner should be square, and the dimensions should be calculated as for a beam equal in length to the longest unsupported part of the purlin.

Sometimes it may be desirable to have only one stay in the centre, instead of two as in Fig. 84. To find the diameter of the rods in this case, multiply the square root of the gross weight in cwts. by the decimal 0·14, instead of 0·13 and 0·15 as in the foregoing rules.

The stays C and D should be either of wrought or cast iron. The strains on them would be wholly compressive if they were placed in the direction of the resultant of the stress on the rods A C and C D, or of C D and D B. But placed as in Fig. 84, there will be also a cross strain, to meet which the section of the stays should be proportioned accordingly, and a greater quantity of iron will be required in them than if they had to resist a compressive strain only.

The method of strengthening beams with wrought-iron flitches, as described in Art. 201, might also be used for purlins, besides a variety of other methods, for which the reader is referred to the Section on Bridges.

COMMON RAFTERS.

265. Common rafters are uniformly loaded, and the breadth need not be more than from 2 inches to $2\frac{1}{2}$ inches. The depth may be found by the following rule:—

RULE.—Divide the length of bearing in feet, by the cube root of the breadth in inches, and the quotient multiplied by 0·72 for fir, or 0·74 for oak, will give the depth in inches.

Example.—Let the length of bearing of a rafter of Riga fir be 7 feet, and the breadth 2 inches. The cube root of 2 is 1·26 nearly; therefore $\frac{7 \times 0{\cdot}72}{1{\cdot}26} = 4$ inches, the depth required. See Table 15.

Foreign fir makes the best common rafters and purlins, because it is not so liable as oak to warp and twist with the heat of the roof in summer: much, however, depends on the quality of the timber, as oak from old trees often stands very well.

SECTION V.

OF THE CONSTRUCTION OF DOMES OR CUPOLAS.

266. A dome or cupola is a roof, of which the base is a circle, an ellipse, or a polygon, and its vertical section a curve line, concave towards the interior. Hence domes are called circular, elliptical, or polygonal, according to the figure of the base.

The most usual form for a dome is the spherical, in which case its plan is a circle, and section a segment of a circle.

The top of a large dome is often finished with a *lantern*, which is supported by the framing of the dome.

267. The interior and exterior forms of a dome are not often alike, and in the space between, a staircase to the lantern is generally made. According to the space left between the external and internal domes, the framing must be designed. Sometimes the framing may be trussed with ties across the opening; but often the interior dome rises so high that ties cannot be introduced: in the latter case, the observations made on the equilibrium of domes in Sect. 1, Arts. 69, 73, should be attended to.

Accordingly, the construction of domes may be divided into two cases, *viz.* domes which admit of horizontal ties, and domes without such ties.

Domes which admit of Horizontal Ties.

268. A truss for a dome where a horizontal tie can be introduced is shown by Fig. 1, Plate XXIX. In this figure A A is the tie; B B posts, which may be continued to form

the lantern; C, C, are continued curbs in two thicknesses, with the joints crossed and bolted together; D D, a curved rib to support the rafters. This design is calculated for a span of about 60 feet, and may be extended to 120 feet.

Two principal trusses may be placed across the opening parallel to each other, and at a distance apart equal to the diameter of the lantern, as A B, C D (Fig. 2), with a sufficient number of half-trusses to reduce the bearing of the rafters to a convenient length.

Or, the two principal trusses may cross each other at right angles in the centre of the dome, the one being placed so much higher than the other as to prevent the ties interfering. This disposition is represented in Fig. 3, and is the same as that adopted for the Dôme des Invalides, at Paris, of which the external diameter is nearly 90 English feet.

As the dimensions of the parts must depend chieny on the weight of the lantern, it is scarcely possible to give any general rules for them which would be satisfactory. The dimensions of the timbers may however be easily ascertained for any particular design, from the rules and principles laid down in Sects. I. and II.

Domes without Horizontal Ties.

269. The construction of domes without horizontal cross-ties is not difficult when there is a sufficient tie round the base. The most simple method, and one which is particularly useful in small domes, is to place a series of curved ribs so that the lower ends of those ribs stand upon the curb at the base, and the upper ends meet at the top, with a sufficient number of intermediate braces to prevent the ribs from yielding laterally.

When the pieces are long, and so much curved that they cannot be cut out of timber otherwise than across the grain, which reduces their strength, they should be put together in

thicknesses, with the joints crossed, and well nailed together; or, in very large domes, they should be bolted or keyed together. The manner of forming these ribs has been already described, as applied to roofs (see Sect. IV., Art. 241). The method of making curved ribs in thicknesses has been adopted in the construction of centres for arches from the earliest period of arch building; and it was first applied to the construction of domes by Philibert de Lorme,* who gives the following scantlings for different sized domes:—

For domes of	24	feet	diameter	8	inches	by	1 inch.
”	36	”	”	10	”		$1\frac{1}{2}$
”	60	”	”	13	”		2
”	90	”	”	13	”		$2\frac{1}{2}$
”	108	”	”	13	”		3

These ribs are formed of two thicknesses of the scantlings given above, and are placed about 2 feet apart at the base. The rafters are notched upon them for receiving the boarding, and also horizontal ribs are notched on the inside, which gives a great degree of stiffness to the whole.† Fig. 1, Plate XXX., is a section of a dome constructed in this manner, and Fig. 2 a projection of a part of the dome, with the rafters and inside ribs.

When a dome is of considerable magnitude, the curve of equilibrium should pass through the middle of the depth of the ribs, particularly if a heavy lantern rests upon them. This curve will be found by means of Art. 71 or 72, Sect. 1. Otherwise the ribs should be within the curve of equilibrium, and they ought to be strutted to prevent their bending in. Or, if it be necessary for the external appearance of the dome

* See his ‘Nouvelles Inventions pour bien Bâtir à Petits Frais,’ 1561.

† Mr. Price proposes a similar mode of forming bridges and domes in his ‘British Carpenter.’

that the curvature of the ribs should be without the curve of equilibrium, then an iron hoop may be put round at about one-third of the height to prevent the dome bursting outwards. This latter method was adopted in the external dome of the Church de la Salute at Venice; the outside dimensions of which are 80 feet diameter, 40·5 high, and the lantern 39·5 feet high; but the lantern is supported by a brick dome, which is considerably below the wooden one. The ribs of this dome are 96 in number, and each rib is in four thicknesses; the four together make 5·5 inches, so that each rib is 8·5 inches by 5·5 inches. The iron hoop is 4·5 inches wide, and half an inch in thickness, and is placed at one-third of the height of the dome.

270. One of the finest applications of the system of De Lorme was the cupola over the Original Halle au Blé at Paris, completed in 1783 (Plate XXXI.). Although 129 feet in diameter* its thickness did not much exceed 1 foot, notwithstanding which it stood in perfect safety until destroyed by fire in 1802. The ribs of which it was composed were formed of planks in 9 feet lengths, 13 inches wide, and 3 inches thick, bolted and tied together after the manner shown by Fig. 80, Art. 241.

At about one-third of the height of the dome from the springing every third rib was discontinued to admit of an opening, which was glazed. The ribs were about $2\frac{1}{2}$ feet apart at the base, and those next the openings were formed with four thicknesses of planks, all the others having only three. At the top of the dome the ribs were framed into a circular ring of timber, leaving an open space which was protected by a glazed canopy, with perforations for the ventilation of the building.

No modern example, executed in wood, has surpassed this

* Emy, Traité de Charpenterie.'

dome, either for simplicity or strength; and the facilities afforded at the present day by the use of wrought iron has probably rendered the execution of domes of this magnitude in wood a thing of the past, except for temporary purposes.

271. When a dome is intended to support a heavy lantern, it may require the principal ribs to be stronger than can be obtained out of a single piece of timber; but the framing may always be made sufficiently strong by using two ribs, with braces between, and tied together by radial pieces across from rib to rib. A truss of this form is shown by Fig. 3, Plate XXX., which would sustain a very heavy lantern if the curve of equilibrium were to pass in the middle between the ribs, as the dotted line does in the figure. The proper form for the curve will be found by the equations in Art. 72, Sect. 1.

Trusses somewhat similar to that shown by Fig. 3, Plate XXX., were used for the roof and semi-domes of the Dublin Exhibition building in 1853. Each truss was formed of two concentric vertically laminated ribs about 5 feet apart, with intermediate diagonal framing, in which both struts and ties were formed of timber. The upper or outer rib consisted of ten lamina $1\frac{1}{2}$ to 2 inches in thickness, and 4 to 18 inches in depth. The breadth of the rib at top was 18 inches, and at bottom only 3 inches, each ply being stepped back from the lower edge of the preceding. The inner rib was formed of six $1\frac{1}{2}$ and 2 inch lamina, and was 12 inches deep and 10 inches wide. The span of the semi-domes of the great hall was 100 feet, and the principal trusses were 25 feet apart.*

272. Where a light dome is required, without occupying much space, the ribs may be placed so near to each other that the boards can be fixed to them without rafters, or short struts may be placed between the ribs, as shown by Fig. 4.

* Mallet's 'Record of the International Exhibition of 1862.'

SECTION VI.

OF THE CONSTRUCTION OF PARTITIONS.

273. Partitions, in carpentry, are frames of timber used for dividing the internal parts of a house into rooms: they are usually lathed and plastered, and sometimes the spaces between the timbers are filled in with brickwork.

In modern carpentry there is no part of a building so much neglected as the partitions. A square of partitioning is of considerable weight, seldom less than half a ton, and often much more; therefore a partition should have adequate support: instead of which it is often suffered to rest on the floor, which of course settles under a weight it was never intended to bear, and the partition breaks from the ceiling above.

If it be necessary to support a partition by other means than a direct bearing on the walls, it should rather be strapped to the floor or roof above it, than be suffered to bear upon the floor below; because in that case the cracks along the cornice would be avoided; but the timbers of the floor or roof must be made stronger. A partition ought to be made capable of at least supporting its own weight, for even when doorways are so placed that it cannot be trussed the whole depth, it is almost always possible to truss over the heads of the doors.

274. Partitions that have a solid bearing throughout their length do not require braces, indeed they are better without them, as they are easily stiffened by means of struts between the uprights, and the shrinking and cross strains occasioned

by braces are thus avoided. When braces are introduced in a partition, they should be disposed so as to throw the weight upon points which are sufficiently supported from below, otherwise they do more harm than good.

Though it be often practicable to give a partition a solid bearing throughout, it is better not to do so, as fractures would be caused by the settling of the walls; the partition should therefore be supported only by the walls to which it is connected, so that both may settle together.

Also, when a partition is supported at one end by the wall of a high part of the building, and by the wall of a lower part at the other end, it will generally crack either close by the walls, or diagonally across; but much will depend on the state of the foundations; if they do not fail, the settlement in the walls, owing to unequal heights, will be very small.

In a trussed partition the rule is that the truss should have good supports, either at the ends or other convenient places, and the framing should be designed so that the weight may not act on any other points than those originally intended to bear it. The best points of support are the walls to which the plastering of the partition joins.

275. Partitions are made of different thicknesses, according to the extent of bearing: for common purposes, where the bearing does not exceed 20 feet, 4 inches is sufficient; or, generally, the principal timbers may be made

4 inches	by	3 inches	for a bearing	not exceeding	20	feet.
5	,,	$3\frac{1}{2}$,,	,,	,,	30	,,
6	,,	4 ,,	,,	,,	40	,,

The filling-in pieces, which are called "quarterings" or "studs" when long, and "puncheons" when short, need not be thicker than about 2 inches, or just sufficient to nail the laths to.

When these filling-in pieces are in long lengths, that is,

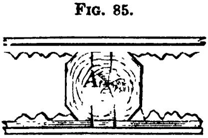
when they exceed 3 or 4 feet, they should be stiffened by short struts or horizontal pieces inserted between them, or, which is better, a continued rail notched across the uprights and nailed to each. In a brick-nogged partition these horizontal pieces, which are called "nogging pieces," are essential. They are usually much thinner than in a lath-and-plaster partition, being seldom more than three-quarters of an inch thick, and the same width as the struts, and placed at about every third or fourth course of the brickwork in height.

It should be borne in mind in all cases that useless timber is an additional load upon the framing, and only increases the risk of failure at a considerable expense.

The thicknesses above mentioned apply only to partitions that have no other than their own weight to bear. When a partition is intended to support a floor, it must be prepared for that purpose. It would, however, be impossible to lay down rules for such cases, as the design will vary according to the circumstances of each, which may differ materially.

The quarterings or filling-in timbers for a lath-and-plaster partition should be spaced at from 12 to 18 inches from middle to middle, according to the length and strength of the laths. In a brick-nogged partition the quarterings should be either 18 inches, 2 feet 3 inches, or 3 feet apart, being a multiple of 9 inches, or the length of a brick.

FIG. 85.



The arrises of all timbers exceeding 3 inches in thickness should be taken off as shown by Fig. 85, to admit of a sufficient key for the plastering.

276. The pressure in the direction of any of the pieces may be found by applying the principles given in Sect. I., and the scantlings of the timbers that would be sufficient to sustain such pressures may be found by the rules for the stiffness of materials in Sect. II. The following data will

assist in forming an estimate of the pressure on the framing of partitions:—

	lbs.	lbs.	
The weight of a square of partitioning may be taken at	from 1480	to 2000	per square.
The weight of a square of single joisted flooring, without counter-flooring ..	„ 1260	„ 2000	„
The weight of a square of framed flooring, with counter-flooring	„ 2500	„ 4000	„

As great nicety is not required in calculating the scantlings, the highest numbers may be taken for long bearings, and the lowest for short ones; one gives the weight in large mansions, the other that in ordinary houses.

The shrinkage of timbers, and still more frequently imperfect joints, cause considerable settlements to take place in partitions, and consequently cracks in the plastering; it is therefore essential that the timber should be well seasoned, and also that the work should be well framed, as even a slight degree of settlement in a partition is attended with worse consequences than in any other piece of framing.

277. Fig. 1, Plate XXXII., shows a design for a trussed partition with a doorway in the middle; the tie or sill is intended to pass between the joisting under the flooring boards. The strongest position for the inclined pieces of the truss is shown by the figure, as the truss would have been much weaker with the same quantity of material if these pieces had been placed in the positions shown by the dotted lines. The inclination of the trussing-pieces should never greatly differ from an angle of 40° with the horizon. The horizontal pieces *a a* are intended to be notched into the uprights, and nailed: in partitions for principal rooms, one on each side might be used.

278. When a doorway is placed near to the side of a room, which is often necessary, in order to render the room either convenient or comfortable, the partition should be trussed

over the top of the door, as shown in Fig. 2. The posts A, B, should be strapped to the truss, and braces may be inserted in the lower part of the truss in the ordinary way; but it would be better to halve them into the uprights, which would have the effect of binding the whole together.

In order to save straps, the posts A, B, are often halved to the inter-tie C D; which, in that case, should be made a little deeper; and perhaps this is the best method, as the tie may always be made strong enough to admit of halving.

Partitions should always be put up some time before they are plastered, so that any imperfection in the joinings caused by the warping or shrinking of the timbers may be seen and rectified in time. This precaution is not so necessary where timber has been a considerable time cut to the proper scantlings, or otherwise well seasoned.

SECTION VII

SCAFFOLDS, STAGING, AND GANTRIES.

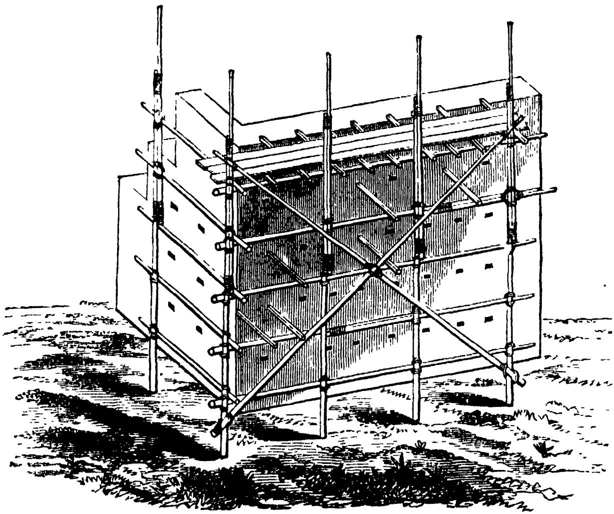
279. A scaffold as used in building is a temporary structure supporting a platform, by means of which the workmen and their materials are brought within reach of the work.

280. The most common form of scaffold is that used by the bricklayer. It consists of poles, usually of fir, from 25 to 40 feet in length, and from 6 to 8 inches in diameter at the butt or larger ends. These poles, which are called "standards," are planted in a row at intervals of 10 or 12 feet, and at a distance from the wall to be erected of about 5 feet in the clear. To the standards on the sides next the wall other poles called "ledgers," placed horizontally, are lashed with ropes, as the work proceeds, at intervals of about 4 feet in height. These support the "putlogs," which are pieces of squared timber about 6 feet long and from 4 inches by 3 inches to 4 inches by 3½ inches in scantling. The putlogs are supported at one end on the ledgers and the other on the wall, a header or half-brick being left out for the purpose in building.

Putlogs are usually placed at about 3½ or 4 feet apart. On them are laid the scaffold boards, which are about 9 inches wide by 1½ inch thick. It is on these scaffold boards that the workmen stand, and the bricks and mortar are deposited. Fig. 86 shows the arrangement of a bricklayer's scaffold. When the scaffold has to be carried to a considerable height other poles are lashed to the standards with ropes tightened by wedges. Poles are also lashed diagonally across every

three or four standards in the shape of a St. Andrew's cross; these are called "braces," and they serve to stiffen or brace the scaffold longitudinally.

FIG. 86.



281. In buildings which do not admit of putlog holes in the walls, as where rubble stone or ashlar facing is used, and which do not require heavy machinery for hoisting or strong timbers in the scaffold, two rows of standards with ledgers are used, one row being close to the wall, and the other at the usual distance, so that both ends of the putlogs may rest on the ledgers.

282. Scaffolds as described in Arts. 280 and 281, are sometimes used for heights of 90 or 100 feet from the ground, as in building church steeples and similar work. The men entrusted with the erection of scaffolds are seldom anything

more than ordinary labourers, and are as a rule wholly ignorant of the principles of mechanics as taught in the schools.

283. In the erection of houses it is usual to construct a staging about 10 feet square on the outside of the scaffolding, for the purpose of hoisting materials, and from which they are distributed for use. This staging is usually formed with standards and ledgers in the same manner as the scaffold to which it is connected.

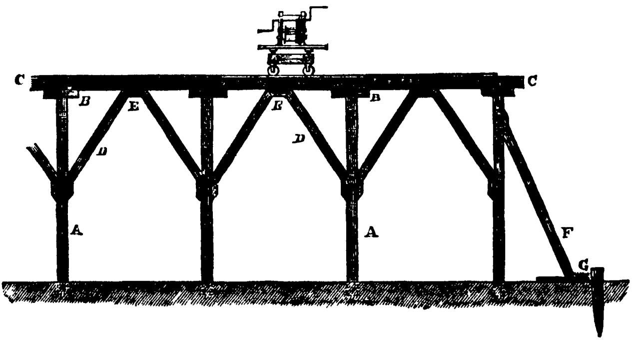
284. In the erection of large works in masonry, the materials used being blocks of stone, frequently weighing several tons, it is obvious that a different arrangement is required from that where the materials can be lifted and set by the hands of the workmen, as in the case of bricks and the small stones used in rubble work. The mason therefore uses, instead of a scaffold formed of round poles, one of squared timbers of large scantling, which being too large to be lashed with ropes are fastened together by bolts and dog-irons, and are kept quite independent of the walls, putlog holes as used in brickwork being inadmissible.

The standards were formerly planted in two rows, one being next to the wall, and a boarded platform was carried on the top similar to the bricklayer's scaffold, the heavy stones being hoisted and set by means of "shears" with blocks and tackle. This method is now almost superseded in large works by a staging formed of squared timbers in the same manner as the mason's scaffold, but with only one row of standards on each side of the wall. On these standards are laid the longitudinal timbers, which usually carry a line of rails on which a travelling platform containing the hoisting gear can move over the entire extent of the building. The standards and longitudinal timbers are made perfectly rigid by struts, disposed as shown by Fig. 87, which is a front view of one tier of the outer row of timbers.

The standards A A are in scantling usually from 8 to 12

inches square, according to the height of the scaffold and the weight to be supported. The distance apart is from 10 to 20 feet. Corbel or "cap" pieces B B are placed under the

FIG. 87.



longitudinal timbers or "runners" C C, to give the latter better bearing on the heads of the standards. The runners C C are usually of the same scantling as the standards; but the struts D D are seldom more than one-half the sectional area of the standards. These struts usually pitch against a straining piece E, which is bolted to the under-side of the runners. The lower ends of the struts rest on cleats, and are secured to the sides of the standards either by iron spikes or bolts.

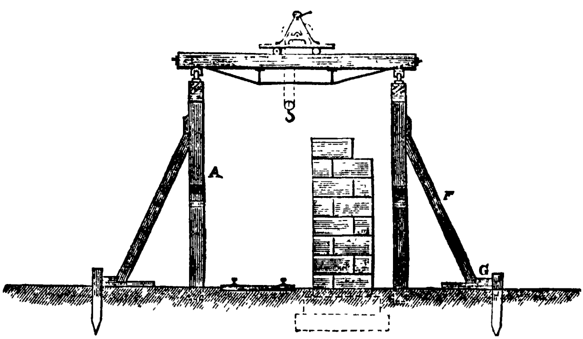
It is desirable to have as few bolt-holes as possible, and to avoid notching, mortising, or otherwise cutting into the timber, so that the deterioration in value at the completion of the work may be as little as possible. Therefore the several pieces are for the most part put together with dog-irons, which are pieces of square or round iron, about $\frac{3}{4}$ of an inch in diameter, having the ends pointed and turned down at right angles. These are driven into the wood, and can be removed with little or no injury to it afterwards.

The distance at which each row of standards should be placed from the wall will depend upon the general arrangement for conducting the works. In some cases a tramway leading from the quarry or stone depôt is laid between the outer row of standards and the wall to admit of the stone being lifted directly from the truck on to the work. In this case a space of from 10 to 20 feet would be required between the standards and the wall.

In other cases, as in the streets of towns, or where the space is limited, the timbers are placed within a few feet of the wall on both sides, and the materials are lifted at some convenient part of the work, over which the "traveller" with its hoisting gear can be brought. Fig. 88 shows a section of a wall in progress with the travelling platform resting on the staging.

To prevent lateral movement in the staging, struts from the ground, as F, Fig. 88, are usually fixed to each standard.

FIG. 88.



The lower ends of the struts should always be fixed to "foot-blocks," as at G, by which they are prevented from sinking into the ground. A short pile should be driven at the outer end of the foot-block, which will prevent it from

slipping. The usual practice, however, is that shown by Fig. 1, Plate XXXIII., in which the foot-block is sunk in the ground at right angles to the direction of the strut. The choice of these methods will depend on the nature of the ground.

Sometimes the ends of the standards are framed with a short or "stub" tenon into a continuous sill of timber placed on the surface of the ground; this prevents the unequal settlement of the standards, which would be fatal to the stability of the staging.

285. In the foregoing description the staging is supposed to be in one tier only; but in buildings which have to be carried to a great height the staging will require to be raised accordingly. This is usually accomplished by placing a beam of timber across the head of each standard, and projecting some 9 or 10 feet beyond it at right angles to the direction of the runners on which it is made to rest, as I I, Fig. 1, Plate XXXIII. This piece, which is called a "footing piece," serves the same purpose as the foot-block G, Fig. 88; but instead of resting on the ground, it is supported by the struts H H, Fig. 1, Plate XXXIII. These struts are usually in two pieces in order that the struts F F may pass between them.

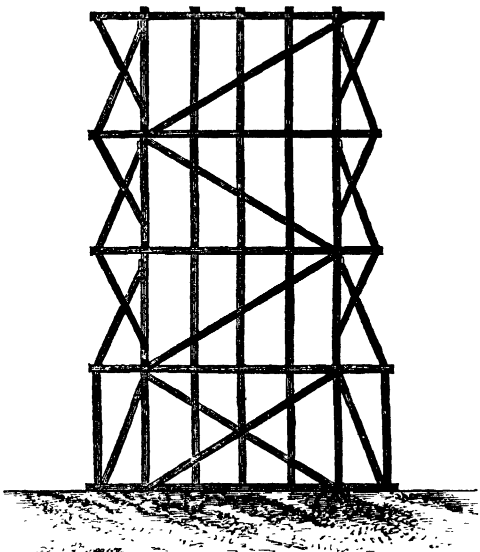
The standards of the upper tiers should always be placed directly over those of the lower tiers to prevent cross strains on the horizontal timbers. Plate XXXIII., Figs. 1 and 2, show the principle generally adopted for staging of this kind, the upper tier being usually braced by diagonal braces as shown in Fig. 2.

286. The term "gantry" is frequently applied to a structure of timber, such as we have described, but properly a gantry is a staging which carries a traveller only, as that shown by Figs. 87 and 88.

287. Fig. 89 is a transverse section showing the arrange-

ment of the timbers of a staging as used in the construction of bridges and viaducts. The width should be from 10 to 20 feet more than the width of the bridge, and the height of the staging is usually about the same as the springing line of the arch. A line of rails is generally laid on each side to

Fig. 89.



admit of a traveller called a "Wellington," which is similar to that shown by Fig. 88, but with the addition of legs to make it clear the upper portion of the structure over which it passes. By means of this traveller all materials, whatever their weight may be, can be hoisted from the ground with the greatest facility, and deposited in the position they are to occupy in the work. In brick arches or those of rubble stone such a traveller would not be required.

In viaducts of great height a staging, as Fig. 89, is also used to support the centering, or in those formed of iron the girders are put together on it. That used in constructing the land tubes of the Britannia Bridge in 1850 was similar in principle to the staging shown by Fig. 89.

When the arches are of considerable span, two or more of the frames shown by Fig. 89 are required for each arch; they are connected by longitudinal timbers or runners, on which the rails are laid strutted, as shown by Fig. 87; or when the distance between the supports is great, wrought iron tie-rods are used as described for purlins, Art. 264.

Where centering has not to be supported, or in an iron bridge where the girders are not put together in position, a simple gantry, as shown by Plate XXXIII., to carry a traveller is all that is required.

288. The scaffolding used in the erection of domes and roofs of considerable span, as those for large railway stations, is nothing more than a series of standards with longitudinal timbers, and a platform on the top with diagonal braces and struts between the standards, similar to that shown by Fig. 89. The arrangement or plan will of course vary according to the shape and extent of the building. Whole timbers are generally used for both standards, and runners and half-timbers for the struts and braces. The platform is usually formed of planks 3 inches in thickness.

289. Plate XXXIV. shows a sketch of the staging used by the contractors, Messrs. Lee and Sons, in the construction of the Admiralty Pier at Dover, in a depth of water of over 60 feet at high spring-tides. This staging carried a pair of travellers on rails 37 feet 10 inches apart, and also two tramways of 4 feet 10 inches gauge for the trollies which carried the materials to run on, one being on each side of the travellers.

The staging was supported on three rows of piles, from

17 to 20 inches in diameter, and about 90 feet long, but with one splice in each pile above the high-water level. The splices were made good with wrought-iron bands and straps. The piles were shod with iron, and driven into the ground at intervals of 25 feet from centre to centre, and the distance between each row was about 41 feet.

The transverse beams, which were of whole timbers, were in two thicknesses, one above the other, and were secured to the heads of the piles by iron sockets bolted on. Over the transverse beams were laid the runners; those for the traveller rails were formed of two whole balks placed side by side. The tramways were supported by single balks of the same size. A footway about 4 feet 6 inches in the clear was formed in the middle of the stage by planking over the space between the runners of the adjoining traveller ways.

As the staging was liable at times to the wash of a very heavy sea, it was the object of the contractors to construct it so as to offer as little obstruction to the waves as possible, therefore the ties and braces were all made of wrought iron, as shown by the thick black lines in the drawing, and the piles were rounded with the same object. From the great length of the piles under water it was difficult to introduce efficient bracing, consequently to each pile of the outside rows a pair of mooring chains were attached and anchored in the sea, one at a distance of about 490 feet from the foot of the pile, and the other at about 290 feet.

It is rarely that we find a staging erected in such deep water, and it reflects much credit on the skill of the contractors who carried it out.

SECTION VIII.

OF THE CONSTRUCTION OF CENTRES FOR BRIDGES.

290. A centre is a timber frame, or set of frames, for supporting the arch-stones of a bridge during the construction of the arch.

The qualities of a good centre consist in its being sufficient to sustain the weight or pressure of the arch-stones, without change of form while the work proceeds. It should be capable of being easily and safely removed, and so designed that it may be erected at a comparatively small expense.

In navigable rivers, where space must be left for the passage of vessels, and in deep and rapid rivers, where it is difficult to establish intermediate supports, and where there is a liability to sudden floods, the centre should span the whole width of the archway, or be framed so as to leave a considerable portion unoccupied. In such cases some skill is required to make the centre an effectual support for the arch-stones, particularly when the arch is large.

But in narrow rivers, and in those where the above-mentioned inconveniences do not interfere with the work, the framing may be erected upon horizontal tie-beams, supported in several places by piles, or by frames fixed in the bed of the river, in which case the construction is comparatively easy.

In large arches, when the arch-stones are laid to a considerable height, they often force the centre out of form by causing it to rise at the crown, and it is sometimes necessary to load the centre at the crown to prevent such rising; but

this is a very imperfect remedy. Notwithstanding that the subject has been considered by so many eminent men, their works are not much calculated to instruct the carpenter how to avoid this difficulty; indeed the object of most of them seems to have been exclusively to calculate the strength of a centre already designed, instead of showing the principles on which it ought to be contrived; and even in calculating the strength they are imperfect guides, because they have not attempted to find what forces would derange a centre, but only the load that it would support without fracture.*

Smeaton, in his designs for centres, always contrived his scantlings to suit the general sizes of timber obtainable in the market, with the view of saving labour, and of leaving the timber in as useful a state as possible when done with.† This practice is a good one, and ought to be imitated, as a centre or a scaffold is not like a permanent work. Nevertheless, some knowledge of the principle of disposing the parts is necessary, and also of estimating the degree of stiffness required; otherwise more timber may be wasted than if it had been cut to the proper scantling at the first, as all timber that has been used in a centre is more or less injured.

291. Centres are composed of several separate vertical frames or trusses called "ribs," connected together by horizontal ties, and stiffened by braces. When the ribs have to span the whole width of the archway, the offsets of the stonework afford a most substantial abutment for the support of the centre. The ribs of centres are generally placed from 4 to 6 feet apart, according to their strength and the pressure they have to support. In general there is one under each of the external rings of arch-stones, and the space between is equally divided by the intermediate ribs.

* See Pitot on "Centres," Mém. de l'Acad., 1726 · Couplet on ditto, 'Mém. de l'Acad.,' 1729. Frezier's 'Coupe des Pierres, tome iii., p. 408.

† Reports, vol. iii., p. 236.

A bridge of three arches will require two centres, one of five arches requires three centres, &c.

Pressure of the Arch-stones upon Centres.

292. Before proceeding to investigate the mode of framing and stiffness of centres, the point must be determined at which the arch-stones first begin to press upon them, and also the pressure at different periods of the formation of the arch.

It has been found by experiment that a stone placed upon an inclined plane does not begin to slide until that plane has an inclination of about 30 degrees from the horizontal plane,* and until a stone would slide upon its joint or bed, it is obvious that it would not press upon the centre. Also, when a hard stone is laid with a bed of mortar it will not slide until the angle becomes from 34 to 36 degrees. A soft stone bedded in mortar will stand when the angle which the joint makes with the horizon is 45 degrees, if it absorbs water quickly, because in that case the mortar becomes partially set.† Similar results have been obtained by other experimentalists; therefore we may consider the pressure in general to commence at the joint which makes an angle of about 32 degrees with the horizon.

This angle is called the angle of repose, and if we suppose the pressure to be represented by the radius, the tangent of this angle will represent the friction; hence, considering the pressure as unity, the friction will be 0·625. Perronet estimates the friction at 0·8;‡ but it is erring on the safe side to take the lower result.

293. The next course above the angle of repose will press upon the centre, but only in a small degree, and the pressure will increase with each succeeding course. The relation

* Rondelet, 'L'Art de Bâtir.' † Idem.

‡ "Mémoire sur le Cintrement et le Décintrement des Ponts," in the 'Memoirs of the Academy of Sciences' at Paris for 1773.

between the weight of an arch-stone and its pressure upon the centre, in a direction perpendicular to the curve of the centre, may be determined from the following equation: $W(\sin. a - f \cos. a) = P$.

Where W is the weight of the arch-stone, P = the pressure upon the centre, f = the friction, and a = the angle which the plane of the lower joint of the arch-stone makes with the horizon.

294. When the angle which the joint makes with the horizon is	34	degrees	P = ·04 W.
" " "	36	"	P = ·08 W.
" " "	38	"	P = ·12 W.
" " "	40	"	P = ·17 W.
" " "	42	"	P = ·21 W.
" " "	44	"	P = ·25 W.
" " "	46	"	P = ·29 W.
" " "	48	"	P = ·33 W.
" " "	50	"	P = ·37 W.
" " "	52	"	P = ·40 W.
" " "	54	"	P = ·44 W.
" " "	56	"	P = ·48 W.
" " "	58	"	P = ·52 W.
" " "	60	"	P = ·54 W.

But when the plane of the joint becomes so much inclined that a vertical line passing through the centre of gravity of the arch-stone does not fall within the lower bed of the stone, the whole weight of the arch-stone may be considered, without material error, as resting upon the centre. We have thus an easy method of estimating the weight upon a centre, at any period of the construction, or when any portion of the arch-stones is laid, as well as when the whole weight it has to sustain is upon it.

295. As an example, let it be required to determine the pressure of the arch-stones upon 20 degrees of the centre, counting from the joint which makes an angle of 32 degrees with the horizon.

RULE.—Take out of the Table in the last Art. the decimals opposite every second degree for the first 20 degrees, that is, from 32 to 52 degrees, and add them together. Multiply the sum thus found by the weight of a portion of the arch-stones comprehended between 2 degrees: the product will be equal to the pressure of 20 degrees of the arch upon the centre.

Suppose the frames of the centre to be 5 feet from middle to middle, and the depth of the arch-stones to be 4 feet; also, that the space comprehended between 2 degrees of the arch measured at the middle of the depth of the stone is 1·5 foot. The solid content will be found to be 30 cubic feet; and if the weight of a cubic foot of the stone be 150 lbs., the weight of 2 degrees will be $30 \times 150 = 4500$ lbs.

Then adding together the decimals for 20 degrees, that is, from 32 degrees to 52, the sum is 2·26. This sum multiplied by the weight of 2 degrees, or 4500 lbs., gives 10,170 lbs. for the pressure of 20 degrees upon one rib of the centre.

296. It will be seen from the Table that the pressure increases very slowly until the joint begins to make a considerable angle with the horizon; and it is of importance to bear this in mind in designing centres, because the strength should be directed to the parts where the strain is greatest. For instance, at the point where the joint makes an angle of 44 degrees with the horizon, the arch-stone only exerts a pressure of one-fourth of its weight upon the centre; where the angle of the joint is 58 degrees, the pressure exceeds half the weight; but near to the crown the stones rest wholly upon the centre. Now it would be absurd to make the centre equally strong at each of these points; besides, by such a method there would not be the means of applying the strength where it is really required, owing to the interference of ties and braces, that are only an encumbrance to the framing.

When the depth of the arch-stone is about double its thick

ness, the whole of its weight may be considered to rest upon the centre when the joint makes an angle of about 60 degrees with the horizon. If the length be less than twice the thickness, it may be considered to rest wholly upon the centre when the angle is below 60 degrees; and if the length exceed twice the thickness, the angle will be considerably above 60 degrees before the whole weight will press upon the centre.

297. But though the error introduced, by considering all the arch-stones above the joint that makes an angle of 60 degrees with the horizon as pressing wholly on the centre, is not a very considerable one, it may be desirable to use a method that approaches nearer to the truth when the arch is circular. However inclined a joint may be, a certain portion of the force of the arch-stone will be lost in friction, except when the joint becomes vertical. And in any case the pressure perpendicular to the curve of the centre will be expressed by the equation [illegible] $- f$ cos. a) = perpendicular pressure = P. But [illegible] ore convenient to measure the angle a from the ve[illegible]e passing through the crown; then W (cos. $a - f$ sin. a) = P.

If the angle included between the joints of one arch-stone be denoted by a, and the stones be alike in weight, and in the portion of the arch they occupy, then the pressure of any number n of arch-stones upon the centre will be expressed by the equation—

$$\mathrm{W}\left(\frac{\cos.\frac{n}{2}a \times \sin.\frac{n+1}{2}a - f\sin.\frac{n}{2}a \times \sin.\frac{n+1}{2}a}{\sin.\frac{1}{2}a}\right)^{*} = \text{pressure} = \mathrm{P}.$$

The magnitude of the arc a being ascertained, the sines and cosines to a radius of unity may be taken from a table

* This expression is equal to W (sum of cosines of $n\,a - f \times$ sum of sines of $n\,a$), and for the sum of the sines and cosines see Hutton's 'Course of Mathematics.'

of natural sines. But the calculation will be more simple under the following form:—

$$\frac{W \times \sin. \frac{n+1}{2} a}{\sin. \frac{1}{2} a} \times (\cos. \tfrac{1}{2}\, n\, a - f \sin. \tfrac{1}{2}\, n\, a). \qquad [A]$$

The computation becomes easier by using a table of logarithms.

When the arch-stones are small, the pressure upon the centre is greater than when they are large, weight for weight; and as an arch-stone will seldom be smaller than would be embraced by one degree of the arch, the result obtained as above may be assumed as sufficiently accurate, the error being always in excess until each of the arch-stones becomes less than one degree. Now the number of degrees between the middle or crown and the angle of repose is 58; therefore by equation [A] the whole pressure upon the semi-centre may be determined. The equation being arranged thus:

$$W \times \left(\frac{\cos. \frac{n}{2} a \times \sin. \frac{n+1}{2} a}{\sin. \frac{1}{2} a.} - \frac{f \times \sin. \frac{n}{2} a \times \sin. \frac{n+1}{2} a}{\sin. \frac{1}{2} a.} \right) \quad [B]$$

The calculation can be made by logarithms as follows, the usual logarithmic radius being assumed.

Example.—If $a = 1$ degree, $n = 58$, and (by Art. 292) $f = 0 \cdot 625$, we have

$$\text{Log. cos. } \frac{n}{2} a = \text{log. cos. } 29^\circ \quad .. \quad = 9 \cdot 941819$$

$$\text{Log. sin. } \frac{n+1}{2} a = \text{log. sin. } 29^\circ\, 30' = 9 \cdot 692339$$

$$19 \cdot 634158$$

$$\text{Log. sin. } \tfrac{1}{2} a = \text{log. sin. } 0^\circ\, 30' \quad .. \quad = 7 \cdot 940842$$

$$11 \cdot 693316$$

$$\text{Deduct Log. Radius} \quad .. \quad .. \quad .. \quad = 10 \cdot 000000$$

$$\text{Log. } 49 \cdot 36 \quad .. \quad .. \quad .. \quad .. \quad .. \quad = 1 \cdot 693316$$

Log. f = log. 0·625	=	1·795880
Log. sin. $\frac{n}{2}\,a$ = log. sin. 29° ..	=	9·685571
Log. sin. $\frac{n+1}{2}\,a$	=	9·692339
		19·173790
Log. sin. $\frac{1}{2}\,a$	=	7·940842
		11·232948
Deduct Log. Radius	=	10·000000
Log. 17·1	=	1·232948

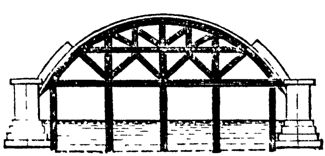
And $49 \cdot 36 - 17 \cdot 1 = 32 \cdot 26$; consequently, $32 \cdot 26$ W is equal to the pressure of the semi-arch upon the centre, where W is the weight of a part of the ring of arch-stones embraced by one degree.

On Designing Centres.

298. A centre should be designed so as to be capable of supporting either a portion or the whole of the weight of the arch without changing its form, and each of its parts should be proportioned according to the pressure, and disposed so as to be free from strains which act too obliquely.

299. Centres for arches of small span are easily managed, and when intermediate supports can be obtained at a comparatively small expense, even large centres are not difficult to construct.

Fig. 90.



The centering of Conon Bridge (Fig. 90), designed by Telford, of which the span is 65 feet and rise 21·8 feet, is a good example.

Fig. 1, Plate XXXV., is another design for a centre with intermediate supports, used for a bridge of Telford's over the River Don. of which the span is 75 feet.

The centre shown by Fig. 2, Plate XXXV., is perhaps one of the best examples of its kind. It was constructed by Mr. Cargil, the contractor, for a stone bridge at Gloucester, of 150 feet span and 35 feet rise, designed by Telford after Perronet's bridge over the Seine at Neuilly. The mode of execution was as follows:—

A platform was prepared perfectly level, on which the centre was struck out to the full size. The timber employed was from Dantzic, in scantlings of about 15 inches square. The piles which supported the centre were of Memel, shod and capped with wrought iron. On these were laid a tier of beams lengthways to the centre, one under each rib, and upon these beams the wedges were fixed, which were of three thicknesses, the bottom one being bolted down to the beams; the tongue or driving piece in the middle was of oak, well hooped at the driving end; the top side of the upper piece was laid perfectly level and straight, both transverse and longitudinally. The wedges were rubbed with soft soap and blacklead before they were laid upon each other.

Each rib of the centre was then brought and put together upon a scaffold made upon the top of the wedge pieces, and was lifted up by means of two barges on the river and two cranes on shore.

The scaffold was extended 30 feet beyond the striking end of the wedges, to lay the last ribs upon previously to raising, and for the workmen to stand upon for finally striking. After the ribs were properly braced they were covered with the 4-inch sheeting piles which had been used in the coffer-dams.

This centre was so well formed that when the arch was keyed its sinking was not more than an inch, and it was struck in the short space of three hours. This was performed by placing beams upon the top of the work directly over the ends of the wedges to these beams was fixed a

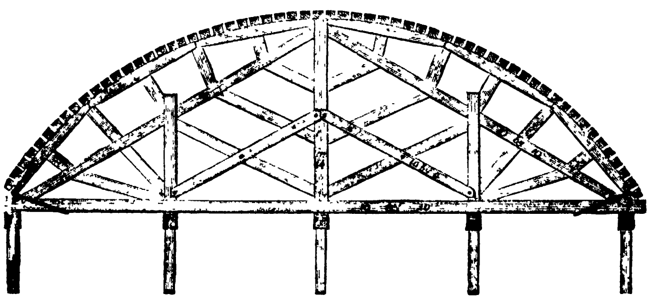
tackle, and at its lower end was slung a ram of 12 cwt., which was swung to and fro, so as to strike the driving end of the tongue-piece of the wedge. This operation required eight men to pull it back and two men to bring it forward; after twenty or thirty blows the wedges started; they then moved easily, and pieces were put in to stop their going farther than was required.

The coverings or laggings were then taken off and the ribs were let down in the same order in which they were put up.

The bearing piles were then drawn by two levers, each 42 feet long, and strong chains.

Fig. 91 shows the centre used for Coldstream Bridge, designed by Smeaton, who says of it, "What I had therefore in view was to distribute the supporters equally under the

Fig. 91



burden, preserving at the same time such a geometrical connection throughout the whole, that if any one pile, or row of piles should settle, the incumbent weight would be supported by the rest.

"With respect to the scantling," he adds, "I did not so much contrive how to do with the least quantity of timber, as how to cut it with the least waste; for, as I took it for granted the centre would be constructed with East County

fir, I have set down the scantlings, such as they usually are, in whole balks, or cut in two lengthways."*

The bridge was of stone, 25 feet wide from outside to outside; the centering consisted of five ribs framed in the manner represented by Fig. 91. The span of the centre arch was 60 feet 8 inches.

In the construction of the Grosvenor Bridge over the Dee at Chester, erected in 1833, the centre adopted by Mr. Trubshaw, the contractor, consisted of back pieces in two thicknesses of 4-inch plank following the curve of the arch, supported by a series of struts radiating somewhat similar to that at the Gloucester Bridge (Fig. 2, Plate XXXV.), in a fan-like arrangement, from iron shoes or sockets placed on the tops of temporary stone piers, of which there were four in the total span of 200 feet. The striking wedges, which were similar to those used at Waterloo Bridge (Fig. 2, Plate XXXVI.), were placed immediately under the laggings on the whole round of the arch, so that any portion might be relieved from support while the remainder were still borne by the centre.

The struts were connected to each other and with those of the adjoining piers by waling pieces bolted to them at distances of from 10 to 12 feet apart vertically.†

300. Where intermediate supports cannot be obtained the design and execution of a centre becomes much more difficult, owing to the necessity of taking precautions to counteract the tendency of the crown to rise when the load is placed upon the haunches. This cannot be illustrated better than by examining the defects of the centre designed by Perronet for the bridge at Neuilly, as shown by Fig. 1, Plate XXXVI. It is obvious that such a centre loaded at A and B must rise at C, and the timbers being nearly parallel, the strains pro-

* Smeaton's 'Reports,' vol. iii., p. 236.

† 'Trans. Inst. Civ. Eng.,' vol. i.

duced by a weight resting on any point must have been enormous; consequently, the yielding at the joints was very considerable. The system here exhibited is well enough adapted to support an equilibrated load distributed over the whole length; but it is one of the worst that could be adopted for a centre which has to support a variable load. An immense quantity of timber must have been consumed without much advantage. It is crowded into so small a space that the centre has a light appearance which has obtained for it the approbation of many, but who were probably incapable of investigating the true principles on which centres should be designed. The centres for the bridges of Nojent Cravant, St. Maxence, and Nemours, were designed on similar principles and were found to be equally defective.

Fig. 2, Plate XXXVI., represents the centre of Waterloo Bridge, designed by Rennie, in which, owing to a better disposition of the timbers, a load at A could not cause the centre to rise at C without reducing the length of the beam D E and that of the one opposite to it. In some of its parts, however, there is an excess of strength besides being very complicated, but on the whole it is not a bad combination. The design appears to have been adapted from the centre used for the late bridge at Blackfriars, designed by Mylne in 1760—with some improvement both in form and construction—which did much credit to the engineer.

In further illustration of the principle of constructing centres without intermediate supports. Let the line A C A′ (Fig. 1, Plate XXXVII.) represent the curve of an arch, and suppose the arch-stones to begin to press upon the centre at B B′, where the joints make an angle of 32 degrees with the horizontal plane, and that the laying of the arch-stones proceed simultaneously on each side. Now if two trussed frames E D H, E′ D′ H′, abut against each other at C, the point C cannot rise in any sensible degree from the pressures

at D, D′, and by adding the piece F F′ with the pieces F I, F′ I′, much additional security will be obtained.

The framing of this centre commences on each side nearly at a point where the arch-stones first begin to press on it. The curved rib must be strong enough to sustain the weight between B D and D C, but the bearings may be shortened by making the abutting blocks at D, D′, longer. The beams E C, E′ C, will act as ties until the arch-stones are laid beyond the points D D′; they will then begin to act as struts and will continue so to act until the whole be laid.

This arrangement cannot be economically employed where the span is large, owing to the length of the timbers required.

Again, let the built beams E F, F F′, and F′ E′ (Fig. 2, Plate XXXVII.), be each trussed, and abut against each other at F and F′, then it is obvious that when the loads press equally at D D′ there will be no tendency in the beam F F′ in the middle to rise unless it is too weak to resist the pressure in the direction of its length; and as it is easy to give it any degree of strength that may be required, a centre of this form may, with a little variation, be applied to any span to which a stone bridge can be erected. When timber of sufficient length is not to be obtained the beams E F, F F′, and F′ E′, may be built in the manner described in another part of this work for building beams.

As a general rule it is advisable to make the piers support the whole weight of the centering, particularly if the foundations be of a yielding nature, as by this means no additional weight is brought on the foundations after the centre is removed, and consequently there is less likelihood of settlement in the arches.

The girder principle, as applied to timber bridges, may in most cases be used with advantage in the construction of centres.

301. Plate XXXVIII. shows the description of centre most frequently adopted for tunnels. The framing is similar in principle to that of a queen-post truss as described in the Section on Roofs. The back pieces of the rib are usually formed of two thicknesses of 3-inch plank bolted together. The distance apart of the ribs is about 5 feet. When raking struts are required to be used in excavating the tunnel, the two leading ribs, or those next to the excavation, should be constructed without tie-beams, to avoid interfering with the struts.

It is hoped that sufficient information has been given to enable the reader to obtain a clear notion of the arrangement required for the centre of an arch, and that he will have no difficulty in applying the principles here indicated to one of any form or span.

On the Construction of Centres.

302. The principal beams of a centre should always abut end to end when it is possible. A very good method, where timbers meet at an angle, is to let them abut into a socket of cast iron, as in the centre of Waterloo Bridge. (See Fig. 2, Plate XXXVI.) The timbers should intersect one another as little as possible, as every joining increases the danger of settlement, and halving the timbers together destroys nearly half their strength. The pieces which tend towards the centre, and those which perform a similar office to the king post of a roof, should be notched upon the framing; they should be in pairs, that is, one on each side of the frame, and well bolted together. Most of the braces may also be applied in the same manner with advantage. The braces marked *a a*, in Fig. 2, Plate XXXVII., are supposed to be done in this way.

Ties should be continued across the frames in different places, particularly where many timbers meet; and diagonal

braces between the ribs are also necessary, to secure them from lateral motion.

A sound and firm centre is a most desirable thing in the construction of an arch, as the motion of a weak one destroys the cohesion of the cementing materials. Sometimes centres have completely failed from inattention to these principles. In erecting a large arch over the river Derwent, on the line of the Glossop and Sheffield road, as they were proceeding to lay the key-stone, the centre gave way, and fell with a tremendous crash into the river. Several lives were lost.*

On Removing Centres

303. The frames or principal supports of a centre should be placed upon double wedges, or sometimes they may be placed upon blocks with wedge-formed steps cut in them; and when the centre is to be eased, the wedges, or wedge-formed pieces, are driven back so far as to suffer the centre to descend regularly, as described for the centre of Gloucester Bridge. (Art. 299.) This operation should be very gradually performed; in order that the arch, in taking its proper bearing, may not acquire any sensible degree of velocity; as it would be dangerous to let it settle too rapidly.

In small centres the wedges are driven back with mauls, men being stationed at each pair of wedges for that purpose. But in larger works a beam is mounted, as a battering-ram, to drive back the wedge-formed blocks. Before driving back the wedges a good precaution is to mark them, so that it may be easy to ascertain when they are regularly driven. As soon as the arch is completed, the centre should be eased a little, in order that the arch-stones may take their proper bearings before the mortar becomes hard, otherwise the joints will crack on the arch settling.

* 'Morning Chronicle' of August 27, 1819.

It is a great advantage in striking centres to have the power of allowing them to rest at any period of the operation; and in this, as well as in other respects, the methods of lowering and easing centres practised in Britain, are superior to those sometimes adopted by the French engineers. The French method consists in destroying, by little and little, the ends of the principal supports; a work of difficulty as well as of danger, and which cannot be done with so much regularity as with wedges.

A method of striking centres which is considered superior to any of the foregoing was adopted by M. Bouziat at the Bridge of Austerlitz in Paris, in 1854, and subsequently for several bridges erected in India. It consisted of iron cylinders about 12 inches diameter and 12 inches high, open at both ends, placed in a vertical position on a wooden platform, which formed the lower striking plate of the centre. The cylinders were prevented from slipping by being placed on circular disks of wood $\frac{3}{4}$ of an inch thick nailed to the platform, and fitting the interior diameter of the cylinders, which were filled to within 2 inches of the top with fine dried sand. Into the space on the top of each cylinder was fitted a solid block or piston of wood about 10 inches high, making a total height of 20 inches.

The whole apparatus was then introduced under the centres in lieu of wedges.

The method of striking consisted of letting out the sand gradually through four holes about $\frac{3}{4}$ inch diameter, which had been drilled in the sides of the cylinder, near the base, and stopped with corks.

In adopting this method care should be taken not to let the sand get wet during the construction of the arch, as it would prevent its running out freely.

The centres of Mylne's Bridge at Blackfriars and those of Waterloo Bridge were placed upon blocks, with wedge-

formed steps cut in them; as is shown in Fig. 2, Plate XXXVI. Another method consists in forming the steps on beams that reach across the whole width of the bridge, passing between the feet of the trussed frames and the posts that support them. In Fig. 1, Plate XXXVII., the centres are supposed to be done in this manner. The frames being thus placed upon continued wedges, the centre may be struck without it being necessary to have workmen underneath, which is less dangerous, and can be done with fewer men. In consequence of nine men having been killed in removing the centre of a military work, Mr. Richard Williams proposed a similar method to the above, which was used with success at Chatham in 1807.*

On Computing the Strength of Centres.

304. It fortunately happens that simple designs are best calculated for centres; for it would be very difficult to form anything like an accurate estimate of the strength of a complicated one. We will here show some approximate methods of determining the scantlings for the timbers of the designs already given; and add to one of them some examples, in numbers, which will tend further to explain the subject.

In the centre (Fig. 1, Plate XXXVII.) the stress may be considered, so far as it tends to strain the frame E D H; also the stress upon the pieces E H, H′ E′, when the whole load is upon them; and, lastly, the strain upon the posts G K, G′ K′.

First. Let the pressure of the arch-stones between B and C be calculated, if the arch be circular, by Art. 297, and if it be elliptical, by Art. 294. Consider half this weight as collected at D, and acting in the direction D F, which will be sufficiently accurate for our present purpose. Then, by attending to the rules in Arts. 14 and 17, Sect. I., the strains

* 'Transactions of the Society of Arts,' vol. xxxiii., p. 128

in the direction of each of the beams composing the frame E D H will be found; and the dimensions of the pieces that would resist them are to be determined by the rules for the stiffness of beams in Sect. II. or by the rule at the end of this Article.

Secondly. Compute the pressure of the arch between D and C, and consider it as acting at C in a vertical direction; then the strain on the beams E H, H′ E′, will be found by the rules above referred to.

Lastly. Let the whole pressure of the arch-stones between B and C, together with half the weight of the centre itself, be considered as acting at the point E in a vertical direction, and find the dimensions of the supports K G, K′ G′, that would resist this pressure.

But in these calculations it must be observed, that if the length of any of the pieces in feet be less than about 1·25 times the breadth, or least dimension in inches, it will cripple at the joint rather than bend. Thus, if a piece be 8 inches in breadth, then its length must be $1 \cdot 25 \times 8$, or 10 feet to yield by bending.

Therefore, when the length between the points where it is braced is less than in this proportion, instead of finding the scantlings by the rules for the stiffness of beams, they must be determined by the following rule.

Rule.—The pressure upon the beam in pounds divided by 1000 gives the area of the piece in inches, or that of the least abutting joint, if that joint should not be equal to the section of the piece.

As all long pieces in a centre may be rendered secure against bending by cross braces, or radial pieces notched on and bolted to them, this rule may almost always be applied for centres, instead of the rules in Sect. II.

305. In the centre (Fig. 2, Plate XXXVII.) the beams E F, F F′, and F′ E′, constitute the chief support, and the

formed steps cut in them; as is shown in Fig. 2, Plate XXXVI. Another method consists in forming the steps on beams that reach across the whole width of the bridge, passing between the feet of the trussed frames and the posts that support them. In Fig. 1, Plate XXXVII., the centres are supposed to be done in this manner. The frames being thus placed upon continued wedges, the centre may be struck without it being necessary to have workmen underneath, which is less dangerous, and can be done with fewer men. In consequence of nine men having been killed in removing the centre of a military work, Mr. Richard Williams proposed a similar method to the above, which was used with success at Chatham in 1807.*

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305. In the centre (Fig. 2, Plate XXXVII.) the beams E F, F F′, and F′ E′, constitute the chief support, and the

arch being an ellipse, a considerable part of it will bear almost wholly upon the centre. But from what has been shown respecting the pressure of the arch-stones, it would appear that if we take the whole weight of the ring between D and C, and consider it to act in the direction H F at the joining F, it will be the greatest strain that can possibly occur at that point from the weight of the arch-stones. Produce the line H F to *f*, and make *h f* to represent the pressure, draw *h e* parallel to the beam E F. Then, as *h f* represents the pressure of the arch between D and C, *h e* will be the pressure in the direction of the beam F E; and *e f*, the pressure in the direction of the beam F F′: and the beams must be of such scantlings as would sustain these pressures.

Let the weight of the arch from H to H′ be estimated, and if two-thirds of this weight be considered to act at C in a vertical direction, it will be the greatest load that is likely to be laid at that point, and the dimensions for the parts of the truss F C F′ must be found so as to sustain that pressure.

The frame E D F may be calculated to resist half the pressure of the arch-stones between B and H; that pressure being found by Art. 291.

The whole weight of the arch-stones from D to C, together with the weight of the centre itself, may be considered as acting in a vertical direction at E, and the supports at G E should be sufficient to sustain the action of this pressure.

To determine the scantling of that part of the rib which supports the weight between H and C, or D and H, &c., calculate the weight of that part of the arch which rests upon it, and consider it as a weight uniformly diffused over the length. The proper scantling will then be found by the rule in Art. 110. These bearings may be much shortened by lengthening the blocks against which the inclined beams of the truss abut.

Examples.

306. *Example* 1.—To determine the principal scantlings for the centre of a stone arch of 50 feet span according to the design shown by Fig. 1, Plate XXXVII.; a cubic foot of the stone weighing 130 lbs., the depth of the arch-stones being 3 feet, and the ribs 5 feet from middle to middle.

The arch is described with a radius of 26 feet; consequently, 27·5 feet is the radius of an arc passing through the middle of the depth of the arch-stones; and to find the length of this arch for one degree, multiply its radius by ·01745329, which gives ·48 for the length.

And $5 \times 3 \times \cdot 48 = 7 \cdot 2$ feet, the solid content of one degree of the ring of arch-stones. But by Art. 297, $W \times 32 \cdot 26 = 7 \cdot 2 \times 32 \cdot 26 \times 130$ lbs. $= 30{,}195$ lbs. for the pressure of that part of the ring between B and C. Then suppose this pressure to act in the direction D F, and in order to render the operation more simple, call it 31,000 lbs. Draw $d f$, in No. 2, Plate XXXVII., parallel to D F; set off $d f$ equal 31 parts, by any convenient scale; and draw $e h$ parallel to the beam E H; also draw $d e$ and $d h$ parallel to the principal rafters of the frame E D C. Now when $d h$ is measured by the same scale as $d f$, it will measure 70 parts; and as both the rafters make the same angle with straining force, the strain on each will be 70,000 lbs. Let the abutting joint be equal to the section of the rafter, then $\frac{70000}{1000} = 70$ inches for the area of the section of each rafter, or nearly $8\frac{1}{2}$ inches square. The strain in the direction of the length of the tie-beam E H need not be calculated, because when it is sufficiently strong to resist the other strains to which it is exposed, its strength to resist tension will always be above what is necessary.

Our next operation is to calculate the weight or pressure

of the arch-stones between B and C, which may be done by common arithmetic. The weight of one degree of the ring is the same as before, that is, $W = 7 \cdot 2 \times 130 = 936$ lbs., and the space between B and C is 32 degrees; therefore $n = 32$. Hence $\cos. \frac{1}{2} n a - f \sin. \frac{1}{2} n a = \cos. 16^\circ - f \sin. 16^\circ = \cdot 96126 - \cdot 27564 \times \cdot 625 = \cdot 788985$. And

$$\frac{W \sin. \frac{n+1}{2} a}{\sin. \frac{1}{2} a} \times \cdot 788985 = \frac{936 \times \cdot 284}{\cdot 00873} \times \cdot 788985 =$$

24022 lbs., the pressure of the part B C upon the centre.

By drawing lines parallel to the directions of the straining force and the beams, we find the pressure in the direction of the beam E H to be nearly 23,000 lbs.; therefore, $\frac{23000}{1000} =$ 23 inches, the area of the section of the beam: but it must be made a little larger than this, in order to have abutments for the other parts of the truss.

To find the dimensions of the supports required at K G, an approximate rule is given in Art. 304, and calculating according to this rule,

The pressure on the centre has been found to be	31,000 lbs.
The weight of half the centre may be stated at	5,000 „
Therefore the vertical pressure at K will be ..	36,000 „

This force would produce a pressure of nearly 41,000 lbs. in the direction K G; hence $\frac{41000}{1000} = 41$ inches, the area of the support required at K.

Example 2.—To find the strain upon the principal supports of the centre, in Fig. 2, Plate XXXVII.; the depth of the arch-stones being 5 feet, the ribs 5 feet from middle to middle, and the stone 130 lbs. per cubic foot. The pressure of the arch-stones upon the centre, estimated by the methods detailed in Art. 295, will be about 130,000 lbs.; and mea-

suring the proportions of the forces by the diagram, No. 3, Plate XXXVII., the pressure in the direction of the beam F F′ will be 220,000 lbs., and the pressure in the direction F E will be 230,000 lbs.; consequently, the area of the horizontal beam should be 220 inches, and may consist of two beams 10 inches by 11 inches. The area of the inclined beam E F should be 230 inches, and may consist of two beams, 11 inches by $10\frac{1}{2}$ inches each.

Note.—It is observed by Prof. Rankine, "that if there were no friction between the arch-stones, the load upon the centre could be computed exactly. The friction between them, however, renders all formulæ for that purpose uncertain."—*Civil Engineering*, p. 486.

SECTION IX.

COFFER-DAMS, SHORING, AND STRUTTING.

Coffer-dams.

307. A coffer-dam is a watertight wall used to enclose the site of a work for the purpose of laying dry the foundation, as in the construction of sea-walls or the abutments and piers of bridges. Coffer-dams were used in the time of Julius Cæsar, and were described by Vitruvius. Alberti, writing towards the close of the fifteenth century, gives a full description of a coffer-dam adapted for shallow water, and observes "that the foundations of piers should be made in autumn, when the water is lowest."*

A timber coffer-dam may consist of two or more rows of close piling, the space between the rows being filled in with well-punned clay, called "puddle."

308. The thickness of the dam, or distance between the outer and inner rows of piles, will depend on the depth of the water to be resisted, and to some extent on the stiffness of the soil through which the piles of the dam are to be driven.

The common rule for the thickness of a coffer-dam is to make it equal to the depth of water when such depth does not exceed 10 feet, and for greater depths to add to 10 feet one-third of the excess of depth above 10 feet.

When the height of the dam above the surface of the ground exceeds 12 or 18 feet, three and sometimes four or more parallel rows of piles are driven, thus dividing the

* 'Libri de Re Ædificatoria,' First Edition, published in 1485

thickness of the dam into two or more equal divisions, each of 5 or 6 feet thick.*

The height at which the dam should stand above high water will depend on the situation; the more exposed it is, the higher will the dam be required; in ordinary cases 3 feet will be sufficient.

Before commencing a coffer-dam it is usual to dredge out all the loose soil on the site, which if allowed to remain would admit water under the puddle. The ground being thus prepared, piles of whole timber, called "guide piles," are driven at intervals of about 10 feet apart, to mark out the form of the dam; longitudinal timbers, formed of half baulks, called "walings," are then bolted on each side of the guide piles, one pair near the top, and another pair at about the level of low water. These serve the purpose of keeping in their places the intermediate piles, which may now be driven.

309. Fig. 92, which shows the form of the dam used by Telford for the lock at St. Katharine's Docks, is that mostly adopted in deep water. The piles A, A, A, were all of whole timber, each 12 inches square, and shod with iron weighing 15 lbs. The walings B, B, B, were in the first instance of half timbers, 12 × 6 inches, and were placed on both sides of each of the guide piles, but when the intermediate piles were all driven these were removed, and single walings of the same scantling were fixed on the two middle and inner rows of piles, and one waling 12 inches square on the outer row; the top walings of the inner row being double, as shown on Fig. 92.

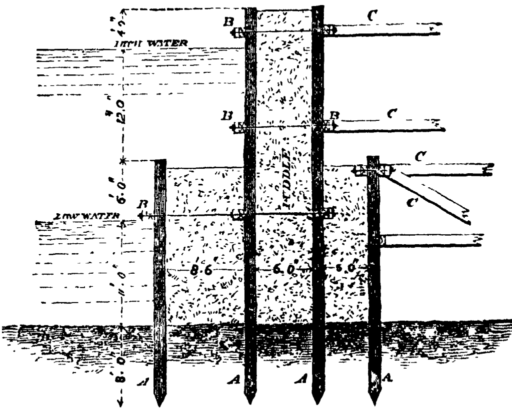
The rows of piles were tied together with iron bolts, which passed through the piles and walings, and were secured with large nuts and washer plates.

All the piles used in a coffer-dam should be matched previous to their being driven, so that they may fit close

* Rankine, 'Engineering.'

together, and prevent leakage through the joints as much as possible.

FIG. 92.



The length of the piles will depend on the nature of the soil and height of the dam. For a depth of water of 5 feet on a soft silty bottom, 25 feet in thickness, Mr. Hughes recommends that piles of 45 feet long should be driven 8 or 10 feet into the solid ground under the silt. For such a depth of water a double dam formed of three rows of piles would be required.

When the depth of water in a tidal river is 10 feet at low water and 28 feet at high water, on a bottom of loose gravel and sand 12 feet thick, with clay underneath, the dam should have four rows of piles. The heads of those of the outer row should be driven down to within 1 foot of low-water mark and 5 feet into the clay, making a total length of 28 feet. The two middle and inner rows to be driven to the same depth into the clay, the former to stand 3 feet above high water, making a total length of 48 feet, and the latter about

11 feet above low-water mark, making the length of the piles 38 feet.

A double row of waling-pieces should be placed all round the tops of the piles, and be connected by wrought-iron bolts $1\frac{1}{4}$ inch square.*

Owing to the great pressure to which the sides are exposed in deep water, coffer-dams require to be strutted from the rear; this is usually effected by forming counterforts of piles at short intervals, according to the strength required. These piles should be tied together with walings and stiffened by struts, and the portion of the dam between the counterforts should be strengthened by horizontal struts from the ends of the counterforts. In dams enclosing a narrow space, as in those for the piers of bridges, the strutting might be effected from opposite sides, but they should be so arranged as to be easily removed and refixed, if required, as the work proceeds.

Struts in the body of the dam at a level much below high water are objectionable, as they would hinder the packing of the puddle and be a fruitful source of leakage afterwards, from the water creeping along them and causing the puddle to settle.

Iron bolts in the body of the dam, though also a source of leakage, are indispensable, in order to prevent the dam from bursting by the swelling of the puddle. These bolts should pass through the piles and be secured by nuts with iron plates, and large wood washers under both the heads and nuts, to prevent them working into the walings from the constant straining to which the dam is subject by the rise and fall of the tide.

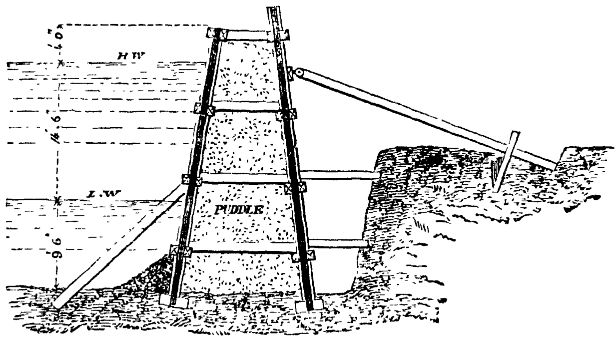
In double dams these bolts are never allowed to go quite through from one side to the other, but if possible to break

* Hann and Hosking, 'Theory, Practice, and Architecture of Bridges.'

joint, as it were in the body of the dam. The bolts in the lower part of the dam (Fig. 92) are shown to go through the outer and middle rows of piles only.

310. Fig. 93 shows a form of dam which was used in 1849 for shutting off the sea from the southern end of the Sunderland Docks, with the view of permitting a further extension of the dock if required.

FIG. 93.



This dam, which is well adapted for a half-tide dam, was constructed inside of a temporary barrier which had been erected to keep out the water while the site of the dock was being excavated. The thickness of the dam was 8 feet at the top and about 16 feet at the bottom, the total height being 28 feet It was formed with guide piles of whole timbers at intervals of about 9 feet, to which the walings were bolted, and the intermediate spaces between the guide piles were filled in with sheeting piles of half timbers 12 inches by 6 inches. "The dam was designed so as to allow the timbers and vertical sheeting to be drawn without running off the water from the dock, and the interior clay to be taken out by dredging. The piles and sheeting were secured to sills laid in chases cut in the rock, strutted to it

at the bottom, and tied to it by iron rods, with split lewis bolts at the top; the former, with the view of removing it and the adjacent rock at a subsequent period, and the latter to guard against the pressure of the earth forcing the upper part of the dam towards the dock before the admission of the water, and afterwards, if the water should by any necessity be reduced to a lower level than usual." *

Wooden struts were used in the body of the dam, but they were arranged so as to interfere as little as possible with the packing of the puddle.

311. The foundations for piers and other detached works under water, when the site is rock, can be prepared at less cost by means of the diving-bell and diving-dress than by a coffer-dam; but cases frequently occur, as in the erection of wharf walls and similar works, where a coffer-dam is desirable. A simple arrangement for constructing a coffer-dam on rocky ground covered by water was adopted by Mr. David Stevenson in 1839, for works in the river Ribble.

Fig. 94.

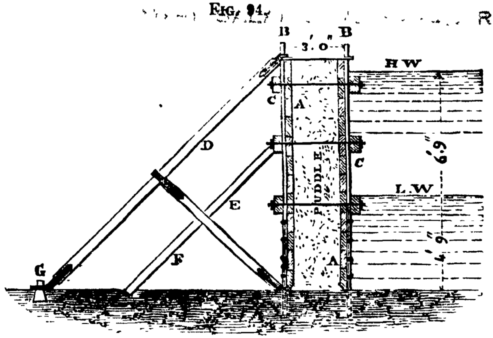


Fig. 94 shows the principle on which this dam was constructed. It consisted of two rows, 3 feet apart, of Memel planks, A, A, 3 inches thick, placed horizontally and held in

* 'Min. Proc. Inst. C. E.,' 1855–56.

their places by iron rods, B, B, $2\frac{1}{2}$ inches diameter, which were inserted in the rock at intervals of 3 feet apart in each row. The two rows of rods and planking were tied together by transverse bolts passed through the body of the dam, and fixed to horizontal waling pieces C, C, 10 inches by 6 inches, placed on the outside of the vertical rod.

The dam was strutted entirely on the inside by rows of strong struts, D, E, and F, placed 18 feet apart, to avoid interfering with the navigation of the river. The outer stay D (Fig. 94) had eyes made of iron fixed at each end to enable it to be dropped over the upper end of the vertical rod at the top of the dam, and over a pin inserted in the rock at the lower extremity G. A cottar at the upper end kept the stay secure. The counter-stay F was fixed at its lower end by the vertical rod of the dam passing through an eye on the end of the stay, similar to that at G. The other end was strapped to the stay D, which it kept quite secure.

A sluice was placed in the dam at the level of low water to enable the water to be let in should a sudden rise of the river endanger the stability of the dam.

The space between the rows of planking was packed with puddle in the usual way.

The mode of fixing the iron rods is thus described by Mr. Stevenson:—"A jumper point was first worked at the end of each, they were then successively jumped into the bed of the river to depths varying from 12 inches to 18 inches according to the soundness or hardness of the rock; no other method of fixing was used: the planks of the lower tier were then secured to the iron rods by clasps of iron, and slipped down into their places one above the other. The under-edge of the lowest tier of planking, the fitting of which often occasioned much trouble, was cut previously to being put down, as nearly as possible to suit the inequalities of the rock. The plank was then lowered to its place, and a small

piles in the first row was 55 feet, and in that of the other two rows 45 feet, though many of them exceeded 60 feet in length.

The height of the piles above the ground was from 28 to 30 feet, all being driven down sufficiently far to enter a bed of hard clay. The width between the first two rows of piling was 7 feet, and that between the centre and back rows was 6 feet. The front and back rows of piling were secured by five tiers of whole timber double walings; but in the centre row, the three lowest tiers of waling were replaced by bands of wrought iron, 6 inches broad by 1 inch thick, keyed together in lengths of 12 feet, and forming a continuous tie on each side of the piling from the two extremities of the dam. The principal object for adopting these bands in preference to the timber walings was to ensure an uninterrupted surface on both sides of the sheet piling, in order that the puddle might be packed closely against it, without leaving any of those voids which are inseparable from the use of ordinary timber walings in such situations, and which serve as channels for any water that may pass along the bolts through the timber.

The transverse or long bolts were all distributed in such a manner as to "break joint," never passing entirely through the dam, but in every case terminating at the centre row of piling; they were screwed up against the wrought-iron plating between which and the face of the pile a washer of vulcanized india-rubber was introduced. These transverse bolts were $2\frac{1}{2}$ inches in diameter at the lowest tier of walings, diminishing upwards to $1\frac{3}{4}$ inch; and in every bay of 25 feet, that is, between two counterforts, there were six through-bolts for each tier of walings, or thirty in each bay. The washer-plates under the heads and nuts of the transverse bolts were of cast iron, 10 inches square, so as to give a large bearing surface on the timber.

For the purpose of distributing the pressure, a cleat of

hard wood, 5 or 6 feet in length, was introduced between the walings and the washers, under all the bolt-heads on the exterior face of the dam.

The dam was stayed at the back by counterforts placed at intervals of 25 feet from centre to centre. These counterforts were each 18 feet in length from the back of the dam, and consisted of close-driven rows of sheet piling of whole timber, strengthened by tiers of walings corresponding with those on the inner side of the dam and connected with them by strong wrought-iron angle-plates, or knees, 6 feet in length, through each of which one of the long transverse bolts of the dam passed. They were further strengthened by horizontal struts of whole timber from 12 to 13 feet in length, placed diagonally and abutting in cast-iron dovetailed sockets 1 inch thick; of these struts there were three rows in the height of the dam.*

313. The surface of the puddle in a coffer-dam should be covered with a layer of bricks, flags, or planking, to protect it from being injured or washed away. This will serve as a staging on which to deposit materials, or to lay rails for the purpose of carrying a traveller.

314. Coffer-dams should be provided with sluices, to let in the water in case of danger to the dam by the sudden rising of the water on the outside.

315. Both gauge and sheeting piles should have iron shoes, or the breaking of the wooden point would cause the pile to move out of its place in driving. Sheeting piles are usually formed with a chisel-pointed end raking, so that the pile in driving will be forced against the adjoining one, and thus form a close joint.

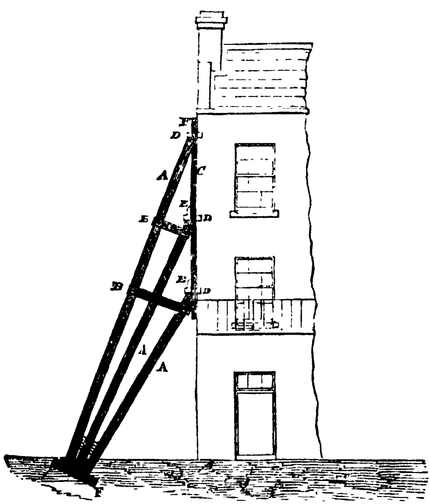
The heads of all piles should be hooped, or "rung," with an iron ring, to prevent them from splitting by the blows of the ram.

* 'Min. Proc. Inst. C. E.,' 1849–50.

SHORING AND STRUTTING.

316. Under this heading it is proposed to describe some of the methods in use for shoring up buildings and for strutting and timbering excavations.

317. Fig. 95 shows the usual method of shoring up a building that is in danger of giving way, whether from defects in the structure, removal of the adjoining buildings, or excavations in the vicinity tending to affect the foundations.



A plank of timber 9 inches wide and 3 inches thick, the length varying with the height of the building, is placed against the upper part of the wall to be supported. In this plank rectangular holes are cut to admit of pieces of timber, called "needles," from 4 inches by 6 inches to 6 inches square and about 12 inches long. The needles are passed

through the plank, leaving about $4\frac{1}{2}$ inches projecting on the outside, and penetrating about the same distance into the wall to prevent the plank from slipping, and on the outside to serve as an abutment for the ends of the struts A, A, A. These needles are shown at DD, Fig. 95. A cleat E is usually spiked to the plank on the upper side of each needle for additional strength.

The struts A, A, A, which are called "shores," are from 6 inches by 4 inches for very small buildings, to 12 inches by 9 inches for large buildings: half balks of timber, or about 12 inches by 6 inches, is a usual size. They are fixed at the lower end on a footing block F buried in the ground, and at the upper end against the under-side of the needles D, D. The outer strut is called the "top raker," and the inner one the "bottom shore," the other being called the "middle raker."

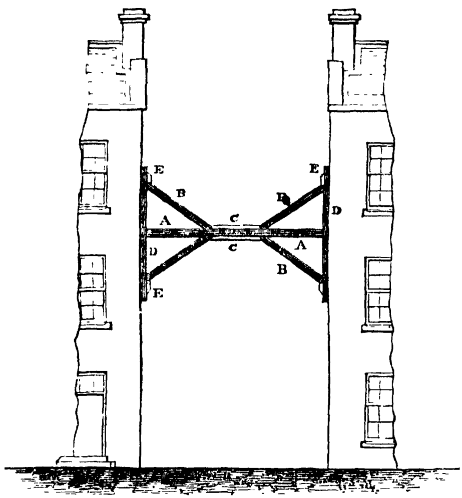
To retain the struts in their places pieces of timber, B, about 1 inch thick and from 6 inches to 9 inches wide, are usually nailed on each side of the struts at a short distance from or immediately under the points where the needles enter the plank. In furtherance of the same object, pieces of hoop-iron are nailed around the lower ends of the struts.

Sometimes, to save length, the top raker, instead of resting directly on the footing block F, is made to spring from the back of the strut immediately under it at a distance of a few feet from the ground, a large cleat being spiked to the back of the strut to assist in supporting it. or a piece of timber is continued to the footing block for the same purpose.

318. In cases of houses where one in a row or terrace is taken down, and the party walls of those adjoining are not sufficiently strong to stand without support, struts are placed between the houses on the opposite sides of the opening, as represented by Fig. 96. D being a plank 9 inches wide and

3 inches thick, similar to that described in the last case, Fig 95, one of which is placed against each wall. Raking struts B, B, are fixed to the upper and lower ends of the plank against the wall, and to the horizontal strut A, which they stiffen. The cleats E, E, and the straining piece C are for the purpose of keeping these raking struts in their places.

FIG. 96.



The horizontal strut A may be from 6 inches by 4 inches to 9 inches by 6 inches, and the raking struts B, B, about 6 inches by 4 inches, depending upon the height and distance apart of the buildings.

319. It frequently happens that the upper portion of the wall of a building has to be supported, while the lower portion is being removed, either wholly or partially, for the purpose of renewing the foundation, forming a doorway, or shop front, &c.

The method of shoring employed in such cases, though requiring extreme care on the part of the workmen, is very simple in principle. It consists merely in breaking one or more small openings through the wall, and inserting a beam or balk of timber in each of sufficient scantling to carry the wall above, and projecting at right angles on each side of the wall to admit of a stout prop being placed under each end. The props are made to rest on wedges to admit of the beam being wedged up tightly against the wall which it supports. The wedges are placed on stout foot-blocks of wood or stone solidly bedded in the ground. If the alterations be extensive, and are likely to be attended with risk, struts, as described in Art. 317, should also be applied to the building where required.

320. Shafts for tunnels, mines, or other purposes, when sunk through soft or loose strata, require to be lined to prevent the soil from being disturbed or the sides from being forced in.

A shaft is said to be "timbered" when it is lined with wood. Brick-lined shafts are always circular on plan, but timbered shafts are usually made rectangular. and they vary in size according to the purpose for which they are intended. 4 feet square gives the smallest area that men can conveniently work in. A shaft of this size is sometimes used for wells, trials, or ventilation; 6 feet by 4 feet is, however, a usual and more convenient size. Winding or working shafts require to be larger; 6 feet by 9 feet to 10 feet square is a usual size for them, and they are sometimes made larger, particularly when they are to be used for the purpose of ventilation as well, in which case they are divided into "upcast" and "downcast" compartments by air-tight divisions called "brattices."

The lining, or "cleading," of a shaft consists of boards, as A, Figs. 97 and 98, from 6 inches to 9 inches wide, which

are placed against the sides and retained in their places by horizontal frames of timber B, B, called "settings."

FIG. 97.

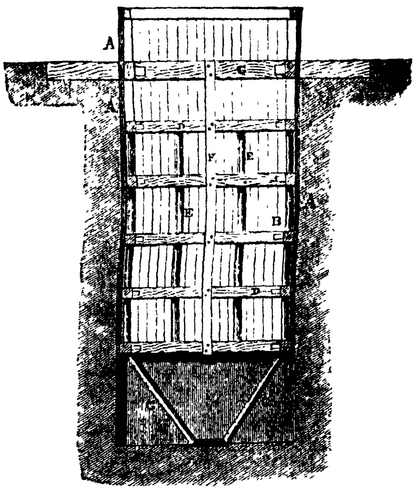
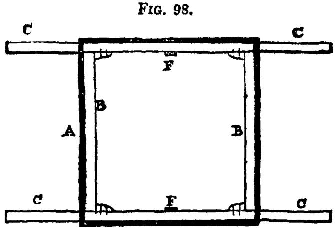


FIG. 98.



The distance apart of these frames is regulated by the nature of the ground passed through, and their scantling will depend on the size of the shaft and on the nature of the ground. Very soft ground requires stronger frames than

merely loose or friable ground, which does not exert so much pressure against the sides of the shaft.

Three feet is the least distance apart the frames are likely to be required even in the worst soils, but it should never exceed 6 feet.

For very small shafts in average ground the scantling of the frames should not be less than 4 inches square. In large shafts 7, 8, and 9 inches are usual sizes. Cleats are used to keep the sides of the frame together, as shown by Figs. 97 and 98. The thickness of the cleading A depends on the distance apart at which the frames are set: when they are *about 3 feet apart, 1 to 1½ inch is a usual thickness*, and when about 6 feet the cleading requires to be 3 inches thick. The former is, however, the safest to adopt in treacherous ground.

The frames are kept apart at the regulated distance by vertical props E, E, Fig. 97, varying according to the weight to be supported, and the length of the props, from 4 to 6 inches in diameter.

To prevent the tendency which the timbering has to slide down the shafts, strips of timber, F, F, Figs. 97 and 98, called "stringers," are spiked to all the frames from top to bottom in succession, and the whole secured to two balks of timber, C, C, Fig. 98, laid on the surface of the ground, one on each side of the shaft. During the sinking of the shaft the last frame put in is supported by raking props, as G, G, Fig. 97.

The method of executing the timbering of a shaft 10 feet square for a coal mine is thus described by Mr. Greenwell: —"Two strong balks of timber, say 12 or 13 inches square, are laid upon the site of the shaft. These balks serve for a purpose shortly to be mentioned. The ground is then dug out to the depth of 3 feet, of such size as to allow the next frame to be laid. After this is done, the inch deals, 6 feet long are set up behind the frame, the bottom ends of the

deals passing down half its thickness, and these deals will rise perpendicularly 3 feet above the surface of the ground, when a light frame, placed within them at the top, will keep them in their places. After this has been done, 6 feet more in depth of ground is taken out and another frame laid, and another 6 feet length of deals put in, also descending half way down this third frame, and of course half-way up the second frame put in, and meeting the bottom of the first length of deals. Then another frame is placed midway between these, and a row of props placed between each set of frames keeps them all level and in their proper places.

"When this has proceeded some depth, and the ground for a still further length is necessary to be taken out, there becomes a tendency for this timbering to slide down, and the balks first named come into use. Planks, called stringing planks, are then spiked to these balks, and also to all the frames, from top to bottom, thus hanging the whole. This may advantageously be done with chains when the whole pressure is downwards. Sometimes, however, it is upwards, although in all cases where this either occurs, or is in the least expected to occur, circular timber is almost indispensable. The entire system to the "stonehead" is a mere continuation of the above.

"The reason why, in the first length, 3 feet of it rise above the surface, is to allow of tip room for the rubbish down to the stonehead."*

Mr. Greenwell further observes that where the surface strata, when of clay, &c., is wet, the above mode of timbering will not be found sufficiently strong, but would be almost certain to collapse at the sides with the pressure. In this case he recommends circular cribs to be substituted for the frames before mentioned.

The internal diameter of the cribs for an 8-feet finished

* 'Lectures delivered at the Bristol Mining School in 1857.'

pit should be 9 feet, and the size of the timber in the cribs being, say, 6 inches square, would allow about an extra foot all round for the walling, with which permanent shafts are frequently lined, the timber being taken out as the masonry is put in.

The mode of putting in these cribs is the same as that of the square frames. The cribs are prepared as follows:—

An accurate floor of wood is prepared, 11 feet in diameter (for a shaft of 8 feet diameter in the clear), in the centre of which is fixed a pivot, on which a radius of 6 feet moves freely, and at $4\frac{1}{2}$ feet from the pivot is fixed an iron point, the use of which is to describe upon the floor a circle 9 feet in diameter.

At short intervals upon this circle spikes are driven in, leaving an inch of their upper part projecting upwards.

The object of this is to form a rest to the inside of the segments during the operation of forming their joints.

The timber from which the cribs are to be cut is divided by being sawn into planking, 6 inches in thickness, and then, by means of a template set to the circle of the shaft or pit, each plank is as economically as possible cut out into as many segments as it will yield. Although it is evident that the inside of the ring, by being the segment of a circle of 9 feet in diameter, will not correspond with the outside, which is that of a circle 10 feet in diameter, yet it is sufficiently near, and thus the same cut that serves for the inside of each segment serves for the outside of another one, or, in fact, the same template will make all the segments. Several segments having been sawn out in lengths varying from 2 to 4 feet, one of them is laid upon the floor, with its inner side resting against the nails inserted as above mentioned, and being pressed close to them two or three other nails are driven into the floor, on its outside, so as to keep the piece of wood firmly in its place. The radius rod is then applied

to the piece, and as large a segment marked out of it with the point of a nail as will leave a 6-inch joint at each end. The end pieces are then sawn off. Another piece of wood is similarly treated and placed end to end with the first; then a third, and so on, until the circle is completed.

Before putting in the last or closing piece, however, it is better to pass a saw through each joint in the line of the radius of the circle, so as to make them more true, and to drive up the pieces as close as possible.

Each circle of cribbing may be sent down the pit in three parts, so many of the short segments as are necessary being nailed together by means of top and bottom cleats of inch-deal, as will make a segment of about one-third the size of the crib. Each of these thirds to have at one end a top-cleat, and at the other end a bottom-cleat, nailed one-half upon it, and the other half projecting, with the nail holes already bored in them so as to allow of their being nailed to the adjoining segment without any delay.

There are some descriptions of soil where even these cribs would be crushed, such as quicksand, which can only be got through safely by iron tubing or strong brick steining.

FIG. 99.

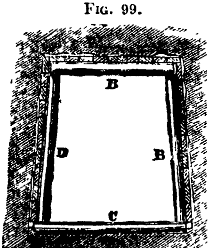
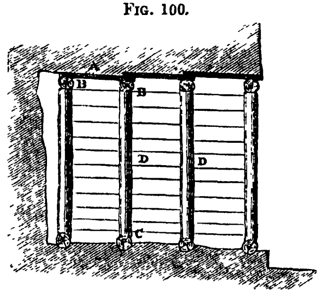


FIG. 100.



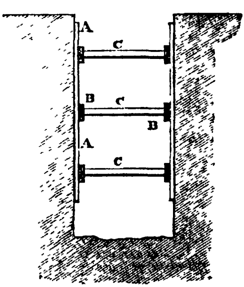
321. Figs. 99 and 100 show the method of timbering a "heading," or gallery, which is usually performed with rough

timber. Sole pieces C, C, from $4\frac{1}{2}$ to 6 inches in diameter, are laid on the ground or floor of the heading. Short pieces of rough boards A, A, called "poling boards," about 1 or $1\frac{1}{2}$ inch thick, are placed against the roof of the heading, underneath which, so as to take the ends of the poling boards, balks of timber B, B, of the same diameter as the sole pieces, are placed and firmly wedged up by the props D, D. To prevent the props from being knocked away or slipping off the sole pieces, spikes, called "brobs," are driven into the sole pieces around the ends of the props.

When the sides of the heading are likely to fall in, poling boards, similar to those on the top, are fixed against the sides, as shown by Fig. 99.

322. Fig. 101 shows the method usually adopted for timbering the sides of trenches and narrow excavations. Poling boards A, A, about 3 feet in length, 1 to $1\frac{1}{2}$ inch thick, and from 7 to 9 inches wide, are placed against the sides of the excavation as each successive depth of 3 feet is excavated. An ordinary deal plank B, 3 inches thick and 9 inches wide, called a "waling," is placed longitudinally against the middle of each row of poling boards. The planks on opposite sides of the trench are kept in their places by struts C, C, laid across and tightly wedged against them. The struts vary in size from 4 inches square to 6 or 8 inches square, according to their length and the pressure they have to sustain.

FIG. 101.



This mode of timbering can be executed as the work proceeds, and the timbers can be readily taken out in parts when required.

323. When the soil is so loose that the sides of the exca-

vation cannot be upheld until a sufficient depth is dug to admit of the insertion of the 3 feet poling boards, long planks, called "runners," usually of deal 3 inches thick and 7 or 9 inches wide, pointed and sometimes shod with iron at one end, are placed behind the walings instead of the poling boards. The walings in this case require to be of stout timber, frequently as much as 12 inches by 6 inches, and the struts should be proportionally strong.

The runners should be constantly driven as the work proceeds, and their points should always be kept about 12 or 18 inches in the ground below the bottom of the trench, to prevent the sides from falling in and to permit the excavation to be carried to the required depth. These runners are, however, difficult to draw out afterwards, and they have sometimes to be left in, which of course adds to the expense.

SECTION X.

WOODEN BRIDGES, VIADUCTS, ETC.

324. The oldest wooden bridge that we have any account of is the Bridge of Sublicius, which existed at Rome in the reign of Ancus Martius, about 500 years before the Christian era, and which it is said was put together without nails or iron of any kind. It owes its celebrity to the combat of Horatius Cocles, a renowned Roman knight, who saved the city by a noble defence of this bridge.

325. The next in point of antiquity was that erected by Julius Cæsar, for the passage of his army across the Rhine. It is described at some length in his 'Commentaries;' and Alberti, Palladio, Scamozzi, and others, have attempted, from the description, to restore the design; but their representations differ considerably. Cæsar's army passed over this bridge ten days after they began to carry the timber to erect it.

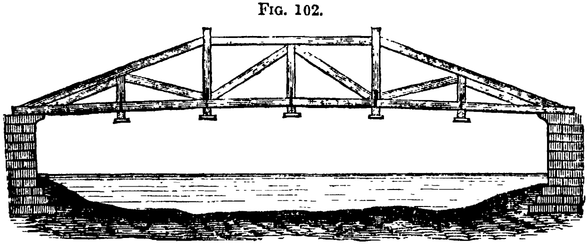
326. The bridge built by Trajan over the Danube appears also to have been of timber, except the piers, which were of stone; at least so it is represented in basso-relievo upon Trajan's Column. The roadway of this bridge appears to have been supported by three concentric curved ribs of timber, connected by radial pieces; and it is certainly a good specimen of the art of building timber bridges at that early period. Trajan's Bridge consisted of twenty or twenty-two stone piers, with wooden arches; each arch above 100 feet span.*

* Gibbon's 'Rome.'

327. In the Middle Ages, when bridges were first established on the passages over the principal rivers, they were almost always constructed with piers, at from 15 to 20 feet apart, consisting of one or more rows of piles. These piers were generally defended by a kind of jetty to break the ice, which also protected them from the shock of bodies borne down by the current: nevertheless, in process of time, and from the frequent repairs that were necessary to protect the piers, the water-way generally became almost wholly blocked up; and consequently the bridge soon became incapable of sustaining the pressure of water which accumulated in high floods.

328. Palladio, in his 'Treatise on Architecture,' has given several designs for bridges, which display a considerable knowledge of the subject; indeed, many of the designs of the present time are merely improvements on those exhibited in his valuable work. Palladio appears to have been the first among the moderns who attempted a mode of construction that would admit of greater spans for the openings, and by reducing the number of piers avoids exposing the timber-work to the shock of bodies carried down by the current. The bridge he erected over the torrent of Cismone, near Bassano (Fig. 102), was of this kind, the span being 108 feet.

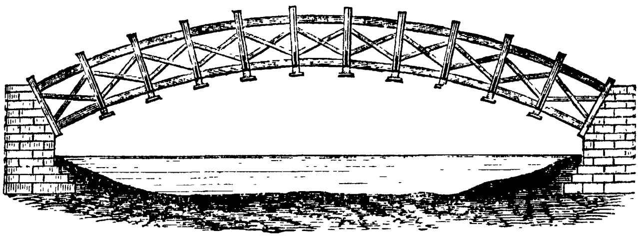
FIG. 102.



Among the designs for wooden bridges given by Palladio, the most remarkable is that exhibited by Fig. 103; as it

appears to have been the first where the idea was adopted of constructing a system of what may be termed framed *voussoirs* similar to those of a stone bridge.

FIG. 103.



329. In Switzerland several excellent wooden bridges have been erected, one of the most celebrated was that at Schaffhausen, constructed in 1757 by John Ulrich Grubenmann, a village carpenter of Tuffen, in the canton of Appenzel, but certainly one of no ordinary capacity. It was composed of two arches, the one 172 feet, the other 193 feet span, supported by abutments at the ends, and by a stone pier in the middle, which remained when the stone bridge was swept away in 1754. In this bridge the oak beams which rested upon the masonry of the abutments and pier not having been sufficiently seasoned, nor raised from the stone-work so as to admit of a circulation of air round them, became rotten, and the frames began to settle. Grubenmann being dead, a carpenter of Schaffhausen, named George Spengler, undertook in 1783 to remedy the defect. He raised the whole bridge, by means of screw-jacks resting upon scaffolding, supported by piles; and replaced the decayed timbers by others of a better quality. This was the only repair that it underwent during the forty-two years of its existence. In 1799 it was burnt by the French army.

The construction is ingenious, the principle of which is

330. The Bridge of Bamberg, on the Regnitz, in Germany (Plate XI.), is an example of a method of construction introduced by Wiebeking. It was built in 1809, and is the widest span that has been executed according to his principle.

It consisted of one arch of 208 feet span, with a rise of 16·9 feet, and the width of the roadway was 32 feet. A stone bridge had formerly been erected on the same site, but its heavy piers contracted the water-way so much, that the water, in a flood, accumulated to such a height as to overturn the bridge by its pressure. In consequence of this accident the wooden bridge was made to span the whole width of the river.

In the middle of the width of the bridge, three ribs were placed side by side, the centre one being five beams in depth at the abutments, and only three in depth at the crown; but those on each side of it were three beams in depth throughout. On each side of the bridge there were two ribs placed side by side, and bolted together; each of these consisted of

* Cox's 'Travels in Switzerland;' Rondelet, 'L'Art de Bâtir·' Gauthey, 'Construction des Ponts.'

five beams in depth towards the abutment, and three beams in depth at the crown. The depth of the beams was from 13·5 to 15·5 inches. The three compound ribs were united together by cross ties, with diagonal stays or braces between.

In the elevation (Fig. 1) the boarding is supposed to be removed from one-half of the bridge, and the abutment cut through, to show the manner of framing the timbers. Fig. 2 is a section to a larger scale across the bridge at A A, on the elevation.

The joints of all the parts built into the abutments were well soaked in hot oil, and they were also covered with sheet lead. The ribs and joists were of fir, the cross ties and plates of oak.

331. In a bridge constructed near Ettringen, by Wiebeking, of which the span was 139 feet and the rise 8 feet, the following method of providing against lateral motion was adopted. Two ribs were placed parallel to each other at the sides of the bridge, and two other ribs were placed diagonally between them, so as to cross in the centre of the bridge.* This method of placing the ribs rendered braces in the flooring unnecessary.

332. Some very light and elegant wooden bridges were erected by James Burn, of Haddington: the largest was over the river Don, seven miles from Aberdeen. The span of this bridge was 109 feet 3 inches, and rise 13 feet 4 inches; the radius of curvature, 119 feet, and the width of the roadway 18 feet.†

333. Plate XLI. shows a timber bridge of 100 feet span, erected by Telford over the river Spey at Laggan Kirk. The arrangement is a judicious one for moderate spans, but

* From Wiebeking, 'Traité d'une Partie essentielle de la Science de Construire les Ponts.'

† 'Edinburgh Encyclopædia,' art. Bridge.

the abutments should be made sufficiently strong to resist the thrust of the raking struts which support nearly the whole weight of the bridge and its load. Bridges on this principle have been used on the Drammen Randsfjord Railway in Norway for spans of 50 and 80 feet.* The design is however, better adapted for common roads, where the traffic is light and where the heavier loads move slowly, than for railways, where heavy loads move at a great speed.†

334. A novel combination of iron with wood is shown by Plate XLII., which is the main truss of a viaduct, designed by I. K. Brunel, to carry the South Wales Railway over the valley of the river Tawe, near the village of Landore; completed in 1850. The entire length of the viaduct is 1760 feet, and the span of the truss shown in Plate XLII., which is that over the river, is 110 feet.

On account of the headway required for the traffic on the river, this truss was placed above the railway. The other trusses, which were of smaller span, were placed under the railway.

The viaduct is terminated at both ends by abutments of masonry. Several of the intermediate supports or piers were formed of timber, as the treacherous nature of the ground rendered it difficult to erect piers of masonry that would stand.

The truss shown by Fig. 1, Plate XLII., is arranged in two rings or series in the form of a polygon, one inside the other, and braced by wrought-iron tie-bars. All the struts in the truss were built of double timbers, each 13 inches by 14 inches, bolted together by 1-inch bolts, about 2 feet 6 inches apart. The struts fit into cast-iron shoes, to which wrought-iron straps are attached, and which perform the respective duties of suspending and main tie-bars. There are two entire sets of straps, one on each side

* 'Engineering,' Jan. 13, 1871. † 'Telford's Life and Works.'

of the truss; the suspending straps on which the roadway is hung being connected to the longitudinal timbers which support the flooring by wrought-iron saddles, which pass underneath the timbers.

The main tie-bar, which is 6 inches by 1¼ inch, is in three lengths, the centre length being drawn up 6 feet 6 inches above the level of the springing to give headway over the river. The suspending straps are 4 inches by 1 inch in cross section, each strap being fitted with two gib-keys and two small cottars, to permit of adjustment. The cottars are kept in position by a bolt passing through them. This was considered preferable to having one through-key, as an opportunity was afforded for correcting any unequal length in the straps. The piers or supports for the truss shown on Plate XLII. were formed of four pieces of timber, each 16 inches square. Three of them were bolted together by 1½-inch bolts, and are perpendicular in elevation, whilst the fourth spreads away from the other at an inclination of 1 in 10, and thus forms a fore-and-aft abutment for the main leg. They are all fitted into cast-iron shoes at the bottom, resting on oak sills laid on piles, which are waled on the face for protection against the river traffic. Fig. 2 shows the method of connecting the legs under the roadway.

There are four of these trusses in the width of the roadway, as shown by Fig. 2, Plate XLII., *viz.* two for the up line, and two for the down line, and they are arranged so that each roadway is complete in itself, by which either pair of trusses can be removed, if necessary, without stopping the passage of the trains. A flooring 8 inches thick is laid across the four trusses, and is supported by the longitudinal timbers which are suspended by the straps already described.

To unite the trusses, four struts, each 12 inches square, two to each truss, are dropped into pockets prepared in the castings, at the crown of the truss, at a sufficient height

above the line of rails to allow the trains to pass under them; and two bolts, 1 inch diameter, one on each side of each strut, and through the castings, unite the trusses of each pair; the pairs of trusses are connected together by bolts and blocking pieces similar to those used for the legs.

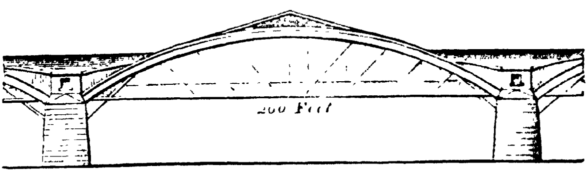
The trusses are stiffened transversely by a set of diagonal struts, 8 inches by 8 inches, under the flooring, and directly over the legs; but the trusses depend mainly for their transverse support on a diagonal outriding tie-rod, shown at *a* in Fig. 2

On the whole, this viaduct shows one of the best methods of combining wood with iron in bridges for railway purposes.*

[illegible]. Passing from the bridges erected in Europe to those of America, we shall find some splendid examples well worthy of the attention of the engineer about to practise in a new country.

Among the earliest of these examples is that erected by Mr. Burr, in 1804, over the Delaware at Trenton (Fig. 104). It consisted of five laminated arches of timber, three of

FIG. 104.



which were 200 feet span, one of 180 feet, and one of 160 feet span. The roadway was suspended from the arched ribs by vertical rods of iron, which were hooked into eyes fixed on the under-side of the ribs. Diagonal braces connect the ribs with the horizontal platform, and prevent any motion taking place in the roadway.

* 'Min. Proc. Inst. C. E.,' 1851-5.

The planks of which the ribs were formed were of white pine, 12 inches wide and 4 inches thick, and from 35 to 50 feet in length, laid close together, breaking joint, and having a uniform depth of 3 feet. The planks or lamina were held together by iron straps, and the ribs were preserved in the arched form by horizontal tie-beams. There were five ribs in the width of the bridge, one being in the middle, and one at a distance of 11 feet on each side, and the outer ones about 4½ feet from these last, forming two carriage tracks and two footways. The versed sine of the ribs over the widest opening was 27 feet. The total width of the bridge from out to out was 33 feet 8 inches. The whole was roofed over to protect it from the weather.*

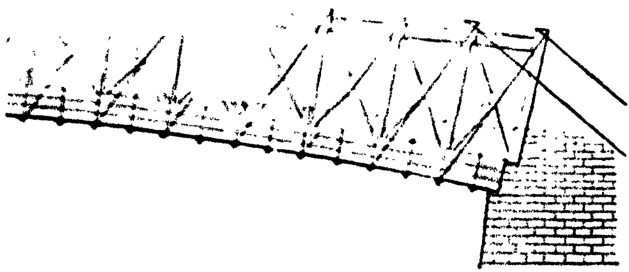
336. A bridge on a somewhat similar principle to the last was constructed over the Susquehannah at Columbia. It was commenced in 1832, and completed in 1834. There were 29 timber arches, each of 200 feet span, supported on two abutments, and twenty-eight stone piers. This is the most extensive arched bridge in the world, its total length, including piers and abutments, being about 1¼ mile.

337. The famous wooden bridge over the Portsmouth River, built from the designs of Mr. Bludget, is another example of the arched-rib principle. It consisted of one arch of 250 feet span, formed of three concentric ribs, placed one over the other at a distance apart equal to twice their own depth. Each rib was formed of two pieces, about 15 feet in length, laid side by side in such a manner as to break joint. The ends all abutted with a square joint against each other, and were neither scarfed nor mortised, but were held together by transverse dovetail keys and joints. The middle rib supported the roadway, and was connected with that above and below it by pieces of hard wood, in pairs, radiating to the centre of the curve, having

* 'Civil Engineering of N. America,' by David Stevenson.

wedges driven between each pair, the ribs being mortised to receive them. The arch was extremely flexible, and would have been improved by diagonal braces between the radiating pieces, after the manner shown by Fig. 10, Plate XLVII.

338. Fig. 105 shows a part of one of the trussed ribs of the celebrated bridge, designed by Louis Wernwag, over the Schuylkill, at Fairmount, near Philadelphia, which was destroyed by fire in 1838.



The bridge consisted of a single arch of 320 feet span, and a versed sine of 38 feet. The width of the roadway was about 30 feet. The principal timbers forming the ribs, which were of large dimensions, were all sawn down the middle for the purpose of ascertaining whether they were perfectly sound. The main ribs consisted of three double rows of timbers, laid three deep, or one above the other, the whole being strongly bound together with wrought iron.

he tops of the king posts, which were made to the centre, straining beams were introduced, which the heads from approaching each other; and, in addition, other timbers, placed diagonally, were inserted in each o divisions for the purpose of strutting the king posts,

and preventing the arch from springing. The abutments against which the timber arch pressed were of solid masonry. The floor of the bridge was supported on girders laid upon shoulders formed in the sides of the king posts, to which they were firmly bolted. On the tops of the king posts, and in the direction of the transverse girders, were laid the tie-beams of the roof, which they served not only to maintain securely, but also to preserve the heads of the king posts in their proper position. The roof was lightly formed, and the sides of the bridge were close boarded so that the timbers could not be seen.*

There was another bridge on a similar principle erected near the same place in 1805, called the "Market Street Bridge," which consisted of three arches, the centre one

A lattice bridge of 200 feet span on this principle was erected, in 1850, over the river Nore, in Ireland, on the Waterford and Kilkenny Railway. The lattice bars, which

* Cresy's 'Ency. of Civil Engineering.'

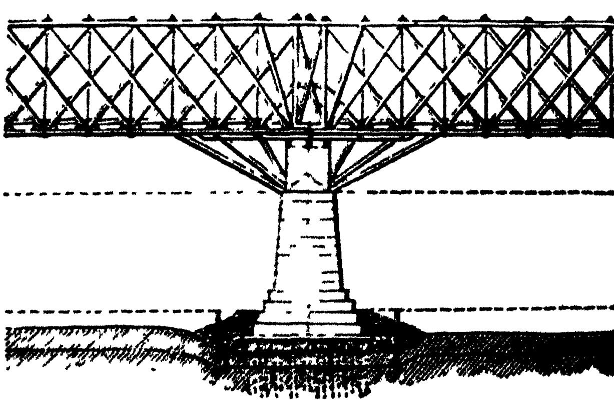
were of Archangel deals, were 7½ inches by
were fastened with iron pins instead of oak treenails.

In 1838 a lattice bridge, 2900 feet in length, was erected over the James River at Richmond, by Moncure Robinson, for the purpose of carrying the Richmond and Petersburgh Railway. The trusses, with spans varying from 130 to 153 feet, were supported on eighteen granite piers.

A similar bridge, 2200 feet in length, was erected by the same engineer across the Susquehannah, the spans of which were each 220 feet.

340. An improvement on the lattice form of bridge is that known as Long's Frame Bridge, shown by Figs. 106 to 109.

FIG 106



This form was frequently applied to spans of 100 to 200 feet. Fig. 106 shows part of the elevation of a Long's Frame Bridge, on the Western Railway, over the Connecticut River, as designed for a span of 180 feet, measured from centre to centre of the piers. The top string, which is shown

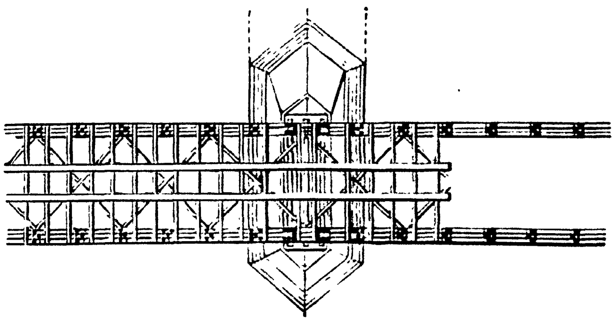
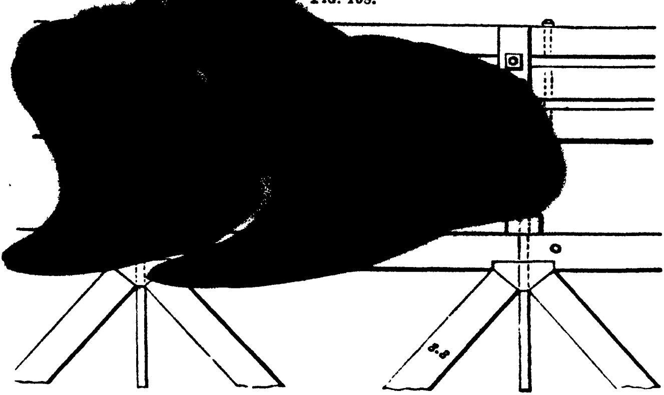


FIG. 108.



the string was increased to 28 inches, to correspond with the bottom string, which was built of six planks, each 12 inches deep, the four inner ones being 5 inches thick, and the two

outer ones 4 inches thick each; the whole together forming a beam 12 inches deep by 28 inches broad. The planks of the upper string were bolted together at intervals of 7 feet, and those of the lower string at intervals of 2 feet.

Short wedge-shaped blocks of hard wood were let into the top and bottom strings to the depth of about 1 inch, as shown in Fig. 109. Into the sides of these blocks were mortised the ends of the diagonal braces; these braces were all 8 inches square, and the number abutting on each wedge-shaped block was always three, arranged two on one side and one on the other, so that in crossing each other the single one, which formed the counter-brace, passed between the other two. Cross pieces of timber, about 7 inches by 5 inches in scantling, were fixed to the top and bottom strings at each wedge-block, to take the ends of the vertical iron rods, which were in pairs, as shown by Figs. 108 and 109.

The transverse beams which supported the roadway, rested upon the bottom string pieces, and were placed one on each side of the abutting blocks throughout the whole length of the bridge.

The platform which carried the roadway was stiffened by horizontal beams placed diagonally between the bottom strings, as shown by Fig. 107.*

In its original form the Long's Frame Bridge had vertical wooden ties to connect the top and bottom strings instead of the iron rods shown in Fig. 106, and the braces were framed into the heads and feet of these ties, and were capable of adjustment by means of wedges.

The improved form shown by Fig. 106, is better known as the Howe Bridge, and the improvement chiefly consisted in the substitution of iron rods for the wooden ties, by which a certain amount of camber could be given.

One of these bridges was erected over the James River at

* Spons' 'Dict. of Engineering,' by Oliver Byrne.

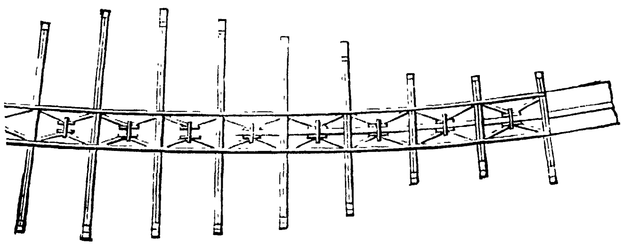
Richmond, on the line of the Danville Railway, the length of which was about 1800 feet, the general span of the openings 121 feet, and the width of the bridge from out to out 18 feet. The number of trusses were two, and their depth 20 feet. The upper strings consisted of two pieces 9 inches by 12 inches, and four pieces 5 inches by 9 inches, having a total sectional area of 396 square inches. The bottom strings consisted of four pieces 6 inches by 12 inches, and four pieces 5 inches by 12 inches, having a sectional area of 528 square inches. The area of the bottom string should always be made greater than that of the upper string on account of the numerous joints. The end main braces—eight in number, four at each end of the bridge—were 8 inches by 9 inches, giving a sectional area of 576 square inches. The counter-braces were 7½ inches by 7 inches; the vertical tie-rods were 1⅝ inch diameter at the abutments and 1½ inch diameter at the centre of the bridge.

341. The additional weight of the trains and other requirements of an increased traffic led to attempts at strengthening the earlier forms of the bridges used on railways. One of these resulted in the Improved Howe Truss, shown by Plate XLIV., which was used for a double line on the Philadelphia and Reading Railway. The clear span was 160 feet. The trusses were three in number and 23 feet deep. The upper strings were composed of four pieces, each 15 inches deep, and together 27 inches in width. The bottom strings also consisted of four pieces, each 20 inches deep by 27 inches total width, keyed and bolted together.

The sectional area of the upper strings of the three trusses was 1215 square inches, and that of the bottom strings 1620 square inches. The arches, in which for the most part consisted the improvement over the ordinary Howe truss, were six in number, one on each side of each truss, and were formed of the best pine, in pieces about 24 feet long by 4¼ inches wide

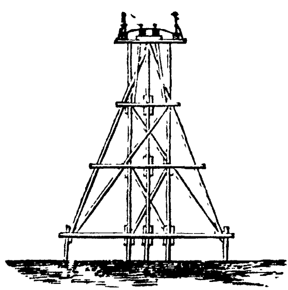
Figs. 110 and 111 show the principle on which these bridges were designed.

They were usually formed of round timbers, the greater number of which were of uniform length.



Each pier was formed of three sets of vertical timbers, assisted by raking struts which sloped inwards so as to meet at the head of the central vertical timber of the pier, as shown by Fig. 112.

FIG. 112.



The piers were crossed at intervals of 20 feet in their height by horizontal timbers, and from the points where the upper row of these cross the piers, diagonals proceeded upwards and inwards, and assisted in supporting the longitudinal timbers on which the rails were laid, directly in the centre of each span. The mode of connecting these diagonals with the longitudinal timbers is shown by Figs. 113 and 114.

The method of forming the junction of the vertical tim-

bers of the piers and the horizontal timbers and diagonals, is shown by Figs. 115 and 116.

It will be seen that in the pier represented by Fig. 117, a second raking strut is shown on the left-hand side.

FIG. 113.

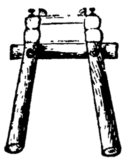


FIG. 114.

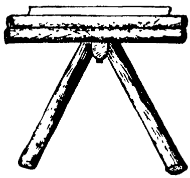


FIG. 115.

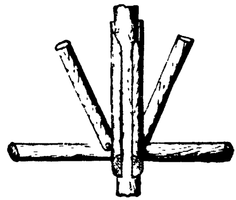


FIG. 116.

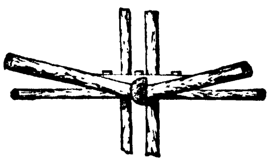
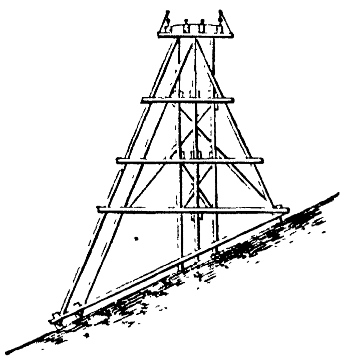


FIG. 117.



These additional struts were only applied on the outside of curved viaducts, straight viaducts having the struts arranged as shown in Fig. 112.

The span between the piers usually adopted for these bridges was 20 feet.*

* 'Engineering,' p. 5, vol. iv.

345.—TABLE of the SPANS of some of the most celebrated WOODEN BRIDGES of EUROPE and AMERICA.

Name	Span of Widest Opening.	Authority.
	feet.	
Bridge of Bassano, over the Brenta, by Palladio (truss)	36·8	Rondelet.
" Cismone, near Bassano, by Palladio	108	"
" Schaffhausen, by Grubenmann, 1757 (truss)	193	Cox's Travels
" Walton-upon-Thames, by Etheridge, about 1758	130	Smeaton.
Bridge of St. Clair, on the Rhone, by Morand, 1775 (truss)	45	Gauthey
Bridge of Tournus, on the Saone, by Gauthey, 1801 .	89½	"
" La Cité, on the Seine, near Paris, by Demoutier, 1802	104	"
Bridge over the Don, near Aberdeen, by James Burn, 1803	109¼	Telford.
Bridge over the Schuylkill, near Philadelphia, by Louis Wernwag (arched rib)	340	Stevenson.
Bridge over the Delaware, New Jersey, by Burr, 1804 (arched rib)	200	"
Bridge of Landsberg, over the Lech, by Wiebeking, 1807 (arched rib)	123	Wiebeking.
Bridge of Irsingen, over the Wertach, by ditto, 1808 (arched rib)	126	"
Bridge of Freysingen, over the Isar, by ditto, 1808 (arched rib)	153	
Bridge of Sharding, on the Rott, by ditto, 1809 (arched rib)	194	"
Bridge of Bamberg, on the Regnitz, by ditto, 1809 (arched rib)	208	"
Bridge over the Portsmouth River, America, by Bludget (arched rib)	250	Douglas.
Richmond Bridge, America, by Ithiel Town (lattice)	150	Cresy.
James River Bridge, on the Richmond and Petersburgh Railway, by Moncure Robinson, 1838 (lattice) ..	153	•
Bridge across the Susquehannah, by ditto	220	
A Long's Frame Bridge over the Connecticut River, on the Western Railway	170	Weale's 'Bridges.'
The Bedford Bridge, a Howe truss strengthened by an arched rib, on the Cleveland and Pittsburgh Railway	243	Zerah Colburn.
The River Nore Bridge, on the Waterford and Kilkenny Railway, by Capt. Moorsom, 1850 (lattice)	200	Moorsom.
Bridge at Rock Island, over the Mississippi (a Howe truss)	250	Zerah Colburn.
The Delaware Bridge, on the New York and Erie Railway (McCallum's principle)	262	"
The Clinton Bridge, on the Galena and Chicago Railway (McCallum's principle in 7 spans)	200	

Observations on the Construction of Bridges.

346. If A B (Fig. 1, Plate XLVII.) be a solid beam resting upon the supports A and B, so as to form one of the girders of a bridge, it will have to carry not only its own weight, but that of the planking and road material, and any heavy body moving over it. Now, in order to strengthen such a beam, without using a larger quantity of timber, we have only to make it deeper in the middle and shallower at the ends, as in Fig. 2, for a strain at C will have less effect in bending the beam than a similar strain in the middle (see Sects. I. and II.). But if the load be sufficient, however it may be distributed, it will cause the beam to bend; in which case the fibres at the upper side *d* will be compressed, and those on the lower side *e* extended. A line may, however, be drawn at the middle of the depth *a c b*, where the fibres remain in their natural state, being neither extended nor compressed. But all the fibres between *c* and *d* are compressed, and all those between *c* and *e* are extended; though not equally so, because the nearer a fibre is to the sides *d* or *e*, the more it is strained. As the intermediate part of the beam is very little strained, particularly near the middle of the length, the material in that part can be more effectually employed by placing it on the top and bottom of the beam, or by forming it into a truss, as Fig. 3, Plate XLVII., where the middle part about the neutral axis is omitted. On examining the forces exerted by the parts of this compound beam, it will be seen that the upper portion *a m d n b* is wholly compressed in the direction of its length, and that the lower portion *a r e s b* is wholly extended in the same direction; and as timber offers the greatest resistance when strained in that direction, provided the joints are made secure, we have in this form an economical method of spanning an opening where the distance between the supports is

not too great. It is also the elementary form of most of the roof trusses described in Section IV. Fig. 4, Plate XLVII., is an adaptation of the same principle which was used in the celebrated bridges of Schaffhausen, Zurich, Landsberg, and Wettingen. The continued tie A B prevents the compressed beams, which form part of the frame, from spreading; therefore this truss requires only to be supported, and has no other thrust on the abutments of the bridge than a solid beam would have. Framed bridges, such as that designed by Palladio (Fig. 102, page 242), may be referred to the same principle. By omitting the tie-beam in the last example, and making the abutments sufficiently strong to resist the thrust of the raking struts, we are led to the form shown by Fig. 5, Plate XLVII. But as long timbers require to be of a proportionate scantling, and cannot always be procured, it is desirable to construct the bridge with short pieces. Hence we are compelled to resort to such a combination as shown by Fig. 6, which is a very common form. It was adopted by Palladio in a bridge across the Brenta, and by Telford for one of 100 feet span over the Spey at Laggan Kirk (Plate XLI.). Although a bridge on this principle might bear a constant load, it is not so well calculated to resist a variable one, which would soon derange it, because the strength of such a system must depend for the most part on the resistance offered by the joints, which cannot be made very strong

347. Fig. 7, Plate XLVII., shows a method similar to that adopted for the timber arches of a bridge of 49 feet span over the Thames near Kingston, erected in 1570. Combinations of this kind naturally lead to the continued curved rib, which possesses advantages not to be found in a series of beams merely abutting end to end; for when the rib is built of short lengths, with the joints crossed, and the several thicknesses firmly bolted together, it becomes nearly as strong as a solid beam. If the straining force be applied at D

(Figs. 8 and 9, Plate XLVII.), it must be sufficient to fracture the rib at C, D and E; therefore, when the strength of the rib is capable of resisting the strains at C, D and E, and the curve is a proper curve of equilibrium to the constant load, this combination is both secure and simple. Its strength to resist a moving load would be much increased by the addition of braces between the upright timbers which connect the roadway to the arch. The use of curved ribs of this kind was known at a very early period, and the system has been further improved by bending the pieces that form the ribs. Bridges of considerable span have been constructed on the principle shown by Fig. 9, as that of Wiebeking's, over the Regnitz, near Bamberg, shown by Plate XL., which was 208 feet between the piers.

348. When the span is considerable, owing to the tendency of a curved rib, in the case of a central or a moving load, to yield at D, C and E (Fig. 8), the strength must be increased by adding to the depth of the rib, which may be accomplished in the manner shown by Fig. 10. The upper and lower members of the rib are connected by radial pieces, and the intermediate space filled in with diagonal braces. In such a case the two curved beams must be continuous and put together so as to resist either extension or compression. With this form no thrust is sustained by the upper rib at the abutments, nor by the under rib at the crown. An advantageous mode of constructing the ribs is with thin lamina, as originally suggested by M. de-Saint-Phar, and used in roofing by Emy (see Art. 242, Sect. IV.).

In cases where it is difficult to form abutments of sufficient strength to enable the tie to be omitted, and it is desirable to keep the headway under the bridge as high as possible, the arched rib may be placed above the roadway, as shown by Fig. 11, Plate XLVII.

Several wooden bridges in America have been constructed

with arched ribs, and of late years the timber arch has been much used to strengthen the lattice and frame bridges of that country.

When the width of the bridge is considerable, a rib may be placed in the middle, so as to divide the roadway into two parts, one being used for the up and the other for the down traffic. The whole may be roofed, or the ribs merely covered, as shown at *a d a′ d′* (Fig. 11, Plate XLVII.).

349. Again, starting from the principle of the straight beam (Art. 346) we arrive at the system of open framework, with horizontal top and bottom strings, as adopted in America. In this form the material to resist compression and extension is placed at the greatest distance from the neutral axis, and consequently the greatest strength is obtained with the least quantity of timber. But as two longitudinal beams merely placed at a certain distance apart, would not act together as a single beam, it is necessary to connect them, as shown by Fig. 12, Plate XLVII.

Each pier has to support a portion of the load on the bridge. This load acts in a vertical direction, and causes a corresponding reaction of equal amount in the girders of the bridge itself, which modern writers on the theory of bridge construction have called the "shearing force," as it tends to cause a separation or shearing of the girder throughout its whole depth at the points of support where it is greatest.

In a solid beam the consideration of the shearing force is usually neglected, owing to the quantity of material near the points of support being more than sufficient in proportion to that in other parts which have to resist cross-breaking or bending; but when that material is reduced, as in the open beam, the case is altered, and the effect of the shearing force becomes important. In several of the earlier American lattice bridges, failure resulted from neglecting to provide for it. Obviously the amount of the shearing force at the

points of support is equal to the weight supported by each, that is to say, in a beam uniformly loaded it would be equal to one-half of the gross load, and it decreases gradually towards the centre, where it vanishes.

When the load is applied at the centre, the shearing force is also equal to one-half of the gross load, but is constant at every point.

If the load is applied at any other point than the middle, the shearing forces on either side are equal to the pressures on the points of support, and are also constant.

The force we have described being vertical will increase on being transmitted through the inclined beams or braces *a*, *a*, Fig. 12, which compose the intermediate parts of an open beam, in the proportion of the length of the inclined brace to the vertical height above its base.

The equal horizontal strains of compression and extension in the open beam are concentrated in the top and bottom strings; they are greatest at the middle of the length when the load is on the middle or uniformly distributed over the length. In other cases the greatest horizontal strain is near the centre of gravity of the load (see Fig. 54, Art. 189).

350. When the opening or distance between the points of support does not exceed 20 feet, a bridge may be constructed by simply laying balks of timber across it of about 12 inches square, trussed with iron rods as shown by Fig. 84, Art. 264. The number of these balks in the width of the bridge will depend on the load to be supported; their scantling may be calculated by the rules given in Art. 264. The strength may be increased by trussing the railing on each side of the roadway. For spanning wide openings, other methods are to be preferred.

351. Where the width of the opening does not exceed 50 feet, curved ribs composed of at least three thicknesses of planks of a convenient length, bolted together side by side,

and the joints crossed or "broken," may be used. The ribs should have as much rise as circumstances will permit, and they should be from 6 to 9 feet apart.

As the weight of the roadway presses in a vertical direction, it should be supported by upright pieces in pairs, notched and bolted to the ribs. The distance apart of the upright pieces should seldom exceed 10 or 15 feet, and horizontal cross ties should be placed at the same points with diagonal braces, to prevent the bridge from vibrating sideways during the passage over it of heavy loads. Diagonal braces should also be inserted between the upright pieces to prevent longitudinal vibration or distortion of the framing.

352. For spans exceeding about 50 feet some difficulty will be found in obtaining timber of sufficient size for the ribs; in such cases beams or planks bent to the curve and placed one above the other may be used. If the beams are of large scantling they should be scarfed at the joinings so as to resist either tension or compression, but if thin planks are used a splayed heading joint is the best.

The number of lamina or thicknesses in each rib will depend on the depth required, and the whole should be well bolted together.

353. Fig. 1, Plate XLVIII., represents a bridge designed for a span of 200 feet, of which Fig. 2 is a cross section to a larger scale taken at C D. This bridge has four ribs, each 18 inches wide and 4 feet deep, in two thicknesses, and may be either four or five in depth according to the size of the timber.

The vertical pieces which support the roadway are intended to be fixed in pairs, notched on to the ribs and bolted together. At each pair of upright pieces a double tie is intended to cross both the back and under-side of the ribs, to which they should be notched; they should also be bolted to the vertical pieces.

Between the timbers which carry the joists of the roadway, diagonal braces should be framed to secure the bridge from lateral motion, where the bridge is subject to the passage over it of heavy loads moving at a considerable speed, as in the case of railway bridges. A series of braces, though not shown on the drawing, should also be framed over the back of the ribs.

The bridge shown by Plate XLVIII. is intended for a gravel or paved roadway, and is calculated to sustain two loaded waggons at its weakest point without injury.

354. For spans greater than 250 feet, instead of single curved ribs, two might be used, one placed above the other, so as to admit of the space between being filled in with a framing of vertical or radial pieces with diagonals between, as shown by Fig. 10, Plate XLVII.

On the degree of Curvature to which Beams may be bent.

355. In designing bridges with curved ribs, it is important to ascertain the degree of curvature that may be given to the beams without impairing their elastic force, as the depth of each piece composing the rib will to a certain extent depend on the result.

The curvature to be given to a beam being sensibly uniform, the degree of uniform curvature to which the beam may be bent is inversely as its depth, and the radius of curvature will be directly as the depth.

Dr. Young has shown that the deflection of a beam uniformly curved is to that of one bent by a load placed in the middle of its length, as 3 is to 2.*

Barlow has determined by experiment the extent to which a beam will bend without the elasticity being de-

* 'Lectures on Nat. Philosophy.'

stroyed.* From this data a rule for the depth of the beams which will admit of a given curvature, may be obtained.

Let x be the deflection found by experiment, upon a beam, of which half the length is y; then $\frac{3x}{2}$ will be the deflection corresponding to a uniform curvature; and $\frac{y^2}{3x}$ = the radius of curvature, the deflection being small when compared with the length.

From Barlow's experiments we have the depth of the beam in inches:—

For English oak	=	radius of curvature	×	·05
For Riga fir	=	,,	×	·035
For Larch	=	,,	×	·077

Wiebeking made some experiments on a large scale by bending beams, which tend to prove the accuracy of this method of finding the depth. He observed, that when several pieces were placed one upon another, they could be bent without fracture much more than a single piece.†

The radius of curvature of the ribs used in the bridge of Bamberg (Plate XL.) was 422 feet, which multiplied by ·035 as above would give 14·77 inches for the depth, whereas the actual depths of the beams employed were from 13·5 to 15·5 inches. The rule giving nearly a mean between the two.

Proportion of Rise to Span in Bridges with Curved Ribs.

356. In a bridge formed of curved ribs, when the rise is limited, whether by the height of the roadway or other local circumstance, the span is also limited; for if the rise does not bear a certain proportion to the span, the bridge will not be

* 'Essay on the Strength of Timber.'

† 'Traité contenant une Partie essentielle.

sufficiently strong to support its own weight and that of the loads passing over it. This proportion depends upon the radius of the curve of equilibrium. The largest span of a bridge executed with timber of which there is any reliable record, is that over the Limmat, near Wettingen, of which the span was 390 feet, the whole rise about 43 feet, and the radius of the curve of equilibrium about 600 feet.*

Wiebeking, in his work on Bridges, gives some proportions for the rise in relation to the span, founded upon observation. He states that *one-tenth* of the span, as far as regards appearance, is the best general proportion for the rise of an arch, but as in most cases it is desirable to keep bridges low, he gives the following:—

For spans from 100 to	150	feet make the rise	=	$\frac{1}{20}$
,, ,,	200	,,	=	$\frac{1}{18}$
,, ,,	300	,,	=	$\frac{1}{15}$
,, ,,	400	,,	=	$\frac{1}{14}$
,, ,,	500	,,	=	$\frac{1}{13}$
,, ,,	600	,,	=	$\frac{1}{12}$

Wiebeking's experience had convinced him that large spans require a greater rise in proportion than small ones.† His practice, however, did not extend beyond spans of about 300 feet: it is probable that greater spans require even more rise than he has assigned to them. The proportions given in the following Table are much safer to adopt, particularly as wooden bridges, however well they may be executed, will always settle a little immediately after being erected, which will increase with time, though in a lesser degree. Wiebeking made some observations on this subject, and found that the settlement in the middle may be expressed in inches by $\cdot 806 \frac{r}{s}$, where r is the rise and s the span, both in feet.‡

* Gauthey, 'Construction des Ponts.'

† Wiebeking, 'Traité d'une Partie essentielle.'

‡ 'Traité contenant une Partie essentielle.'

TABLE of the LEAST RISE for ARCHES of DIFFERENT SPANS.

Span in Feet.	Rise in Feet.	Span in Feet.	Rise in Feet	Span in Feet.	Rise in Feet.
30	0·5	100	5·0	240	17·0
40	0·8	120	7·0	260	20·0
50	1·4	140	8·0	280	24·0
60	2·0	160	10·0	300	28·0
70	2·5	180	11·0	320	32·0
80	3·0	200	12·0	350	39·0
90	4·0	220	14·0	400	53·0

PRACTICAL RULES FOR THE STRENGTH OF BRIDGES.

357. The greatest load likely to meet on a bridge at one time is that produced by a loaded railway train or a dense crowd of people. The former, including the weight of the bridge itself, may be taken, for the purpose of calculation, at 350 lbs., or the ·16 of a ton per superficial foot; and the latter, when the roadway is paved or gravelled, at about 300 lbs., or ·14 of a ton, or at 200 lbs. = ·09 of a ton when the roadway is merely planked.

358. Riga fir, when the length unsupported is such that the piece will not yield by bending, suffers compression in the direction of the length of about 1 part in 1500 under a load of 1000 lbs. upon the square inch. Oak requires a greater load to produce the same compression.*

Under such a pressure the curved rib of a bridge, 200 feet in length, would be shortened rather more than 1·6 inch.

359. BRIDGES WITH CURVED RIBS.—When the load on a bridge is uniformly distributed, the curve of equilibrium is a parabola, and if the form of the rib be made to approximate to

* In Kirkaldy's experiments, a log of white Riga fir 20 feet long and 13 inches square, compressed 1 part in 930 with a load of about $53\frac{1}{2}$ tons (see Table XX., p. 90).

that curve, the load will have no tendency to produce derangement, the strain or pressure being transmitted in the direction of the curve.

The amount of the pressure in the direction of the rib at the crown, arising from a uniformly-distributed load, is the same as the horizontal thrust, and may be determined by the Rules in Art. 40, Sect. I., or by the following method, which is more convenient for our present purpose.

Let P = the strain or pressure in lbs.; R = the rise in feet; S = the span in feet, and W the gross weight of the bridge and its load in lbs.; then, by the resolution of forces, $2\,R : \frac{S}{2} :: \frac{W}{2} : P$ the pressure in the direction of the curve at the crown, or

$$\frac{S \times W}{8\,R} = P. \qquad [A]$$

If b = the breadth of each rib; d = the depth, both in inches; and n = the number of ribs; then $1000\,n \times b \times d$ = pressure, when the rib is sufficiently strong. Combining this with formula [A], we have

$$\frac{S \times W}{8 \times 1000 \times R \times n} = b \times d = \text{sectional area in square inches.} \qquad [B]$$

From this equation we derive the following rule:—

Rule.—Multiply the span in feet by the gross distributed load on the bridge in lbs., and divide by 8000 times the rise in feet multiplied by the number of ribs; and the result will be the sectional area in square inches of each rib at the crown capable of resisting the pressure.

Example.—To find the sectional area at the crown for each rib of a bridge of 200 feet span, and 15 feet rise, capable of supporting a gross distributed load of 1,800,000 lbs., the number of curved ribs being three,

$$\frac{200 \times 1800000}{8000 \times 15 \times 3} = 1000 \text{ square inches.}$$

Such a rib may be formed of three pieces in depth and two in thickness at the crown, similar to those of the bridge near Bamberg (Plate XL.).

360. In consequence of the greater pressure, the sectional area of the ribs at the abutments must be increased to that given by the following rule:—

Rule.—Multiply half of the gross distributed load supported by each rib in lbs. by the square root of the square of the rise of the curve in feet, added to one-sixteenth part of the square of the span in feet, and the result, divided by the rise, will be the pressure in lbs. on the rib at the abutment, which, divided by 1000, will give the sectional area in square inches.

Example.—The span, rise, number of ribs, and load being as in the last example, to find the sectional area of each rib at the abutment.

$$\frac{\sqrt{225 + \frac{40000}{16}}}{15} \times \frac{600000}{2} = 1044030 \text{ lbs.},$$

which, allowing 1000 lbs. to the square inch, gives 1044 square inches nearly for the area at the abutment.

361. The foregoing rules for curved ribs apply only to bridges that are uniformly loaded. When the load is variable, as in the case of a railway train in motion, there is no curve of equilibrium to which the flexible ribs of a timber bridge can be made to approximate, consequently a timber arch, as that used in the bridge at Bamberg, is not well adapted to sustain such a load, unless rendered perfectly rigid by proper bracing.

To calculate the stiffness of curved ribs without braces, the reader is referred to Mr. Guthrie's paper on the subject, given in Arts. 174 to 177, Sect. II.

362. Lattice and Frame Bridges.—These bridges are

subject to a compressive strain along the top string or chord, and to a tensile strain along the bottom string.

The strains are equal when the strings are parallel: they are greatest in the middle of the span, and diminish towards the ends.

The method of finding these strains, on the principle of the lever, was explained in Sect. I., and is given by the following rule, when the load is uniformly distributed over the roadway.

363. *To find the Strain in lbs. at the Centre of the Top and Bottom Strings.*

RULE.—Multiply the span in feet by the weight in lbs. on each truss, including its own weight, and divide by 8 times the depth of the girder or truss in feet.

For every 1000 lbs. of strain thus found allow in the upper string 1 square inch area of cross section, and for every 700 lbs. allow 1 square inch in the bottom string; a greater quantity of timber being required in the bottom than in the top string to compensate for the weakness caused by joints when the pieces are subject to a tensile strain.

Example.—Find the horizontal strain in lbs. on the strings or chords of an ordinary Howe truss bridge having a span of 100 feet and a depth of 12 feet, the gross distributed load on each truss being 75 tons, or 168,000 lbs.

$$\frac{100 \times 168000}{8 \times 12} = 175000 \text{ lbs.},$$

the strain at the centre of the top and bottom strings, which, divided by 1000 for the top and 700 for the bottom, give 175 square inches and 250 square inches respectively for the sectional area of the strings in each truss, and by making the depth 10 inches, the width must be $17\frac{1}{2}$ inches in the top and 25 inches in the bottom.

It is a good practical rule (and one which is observed in Howe's bridges) to make the upper chord or string consist of

three, and the lower of four timbers to each truss; a joint will then occur in each panel, and the pieces should be sufficiently long to extend over four panels. With this arrangement three of the timbers must be supposed to sustain the whole strain, since that which contains the joint is not capable of opposing any resistance.*

364. In a solid beam resting on two supports, the strain at the ends of the strings is nothing, and it increases uniformly towards the centre; but in a bridge truss of a single span there will be a horizontal strain at the end of the brace nearest the abutment, which will equal the weight on the brace multiplied by the co-tangent of the inclination of the brace, which, if 45°, the horizontal strain will equal the vertical weight at the end. If the angle with the horizontal is greater than 45°, (which is generally the case) the horizontal strain will be less than the weight, and consequently it will be safe in practice to assume the horizontal strain at the end of the string, or, more correctly, at the end of the first brace, as equal to the vertical force acting on that brace. This vertical force is equal to one-half of the whole weight on the truss, or in the example given in Art. 363 it will be 84,000 lbs., and the cross section to resist it will be 84 inches.

Having determined the cross section of the strings at the centre and end, a uniform increase between these points will fulfil all the necessary conditions.

365. Another circumstance must be taken into consideration in determining the size of the strings that carry the load directly, and which produces a cross strain upon the portion that lies between any two posts. It is that of a beam supported at the ends and uniformly loaded, or loaded in the middle, as the case may be. The cross section to support this load should be calculated by the rules for the stiffness of beams, given in Section II. In a well-proportioned truss the

* Haupt's 'General T eory of Bridge Construction.'

dimensions calculated to fulfil these last conditions are usually much less than those required in the former case.

366. When the load on a truss is confined to the centre instead of being uniformly distributed, the strain on the strings at the centre will be doubled.

367. *To find the Strains on the Braces or Lattice-bars.*

RULE.—*For the end braces*, multiply that portion of the weight in lbs. supported by the pier (= one-half the gross weight in a uniformly loaded girder) by the length of the brace in feet. The product divided by the vertical height of the brace or distance between the top and bottom strings will give the strain on the brace in lbs. This again divided by 1000 will give the sectional area required for the timber.

Example.—Find the strain and size of the timber for the end braces of a simple truss girder 100 feet span, 10 feet in depth between the strings, the panels 9 feet wide, and the gross distributed load on the girder 168,000 lbs., the length of the brace being 13·45 feet.

$$\frac{84000 \times 13 \cdot 45}{10} = 112980 \text{ lbs.},$$

the pressure transmitted through the brace, and allowing 1000 lbs. to the square inch, the sectional area required is 113 square inches nearly.

368. With a uniform load the strains on the braces diminish from the ends to the middle of the girder until they become nothing.

In practice, as there never is a brace exactly in the middle, those on each side of it must sustain the portion of the load borne by the centre panel, *i.e.* one-half to each brace increased by the length of the brace to the vertical height as for the end ones. Taking the width of the panel at 9 feet, or $\frac{1}{11}$th of the span nearly, the load on each panel of the girder in the last example will be 15,273 lbs., the half of which multiplied by 13·45, the length of the brace, and divided by 10, the

vertical depth, gives 20,542 lbs. nearly for the strain, and allowing 1000 lbs. to the square inch, as before, we obtain a sectional area of $20\frac{1}{2}$ square inches for the brace nearest to the middle of the girder. The intermediate braces can easily be proportioned between these extremes. By the same rules the strains on the braces can be obtained when they intersect one another as in the common lattice, the only difference being that the strain or pressure is divided among a greater number.

369. Where the unsupported length of the brace is considerable in proportion to the diameter, the 1000 lbs. per square inch will not be a sufficient allowance, and the rules for long pillars, as given in Sect. II., must be applied. The braces are seldom so long as to necessitate this; they are almost always in practice supported at one or more points, which reduces the length.

370. When the truss is loaded in the middle only, the braces will all be strained alike, and will equal one-half the load increased in proportion to the length of the brace divided by the vertical height as for a uniform load.

371. *To find the Strains on the Counter-braces.*—As the use of counter-braces is to counteract the effects of a variable load, the greatest strain upon them is equivalent to the greatest strain produced by the same load on a brace, and will be equal to that upon the braces of the middle panel. The sectional area will therefore be uniform throughout.

372. *To find the Strains on the Vertical Rods or Ties of each Panel.*—RULE.—Take the strain on the vertical rod at the abutment as equal to one-half the load on the bridge, and on that next the centre as equal to one-half the load on the middle panel. These rods follow the same rule as the braces under a uniform load in diminishing from the abutment to the centre of the bridge.

373. *To find the Strain upon the Lateral or Floor Braces.*—

The floor-braces are to stiffen the bridge against the effects of high winds, &c., which may be treated as a load uniformly distributed. Half the force will be borne by the braces next the abutments, increased in proportion of the length of the brace to the width between the girders, and diminishing in each brace towards the middle of the span in the same manner as the braces of the girders, Art. 368.

374. *To find the Strain on the Auxiliary Arches of a Bridge Truss.*—When arches are used to strengthen bridge trusses, such as the lattice and other forms on the American principle, the pressure on the arch and size of the timber can be calculated in the same manner as curved ribs (Art. 359). Mr. Haupt remarks with reference to the introduction of arched ribs for the purpose of strengthening trusses, that our calculations must be based to some extent upon uncertain data, for when two systems are combined, we cannot be certain that each sustains an equal portion of the weight; but, on the other hand, we are sure that the assertion sometimes made, that either one or the other necessarily sustains the whole load, is erroneous. Much depends upon the manner of making the connection. If an ordinary truss be constructed, and arches added after it has settled to a considerable extent by the application of heavy weights, it is very clear that the arch will bear but a small proportion of the load; but if the arch is introduced previous to the removal of the false works, and both systems be allowed to settle together, it is fair to suppose that the strain upon each will be in proportion to the respective powers of resistance.

The usual method of constructing bridges is to make the truss of such strength as is supposed to be sufficient to support the weight, and to add the arch as additional security.

Mr. Haupt is of opinion that it is decidedly preferable to reverse this arrangement, making the arch the main dependence, and using a light truss in combination with it, merely

to prevent change of figure in the arch and to give the proper elevation or inclination to the roadway.

It is very evident that an arch can be made to sustain the whole of the weight; for if a truss has settled, it may be raised to any extent, by the addition of arches and suspension rods. In this case, the rule for proportioning the braces, so as to increase in arithmetical progression from the middle to the end, is no longer applicable: there is no more strain at the ends than in the centre, and but little at any point, and in this case the truss is of no other use than to stiffen the arch and carry the roadway.*

Choice of Site for a Bridge.

375. The principal matters to be attended to in the design of a wooden bridge are—1st, the situation; 2ndly, the waterway that ought to be left for the river; 3rdly, the number and span of the openings; and, fourthly, the arrangement and proportion of the several parts. Each of these is chiefly determined by local circumstances.

The principal object in erecting a bridge is to obtain a more easy and ready communication across a stream or valley or between the opposite banks of a river; and, as a rule, the situation chosen ought to be that which is most convenient for the use of the public. Sometimes, however, it happens that the most convenient situation is not the best adapted for the erection of a bridge. In this case the advantages and disadvantages of other situations should be carefully considered, and the site determined so that the means of communication may be as direct as possible, and the access to the bridge convenient.

In the case of a river or stream the choice will be facilitated by making a correct plan of the course, showing the

* Haupt's 'Theory of Bridge Construction.'

banks on each side, and of the roads that are connected with the bridge. This plan should be sufficiently extensive to give a correct idea of the natural features of the surface and of the changes which the bed and course of the river may have undergone.

Longitudinal and cross sections of the water-course should be made, showing the bed of the river, the form of the opposite banks, the nature of the subsoil, the depth of water at different seasons of the year, and the line of the highest and lowest water-marks, which should be drawn from information to be procured from the oldest inhabitants of the neighbourhood.

The nature of the bed of the river should be carefully examined, particularly on the site of the abutments or piers, by boring, driving in a rod of iron, or other means, and to a sufficient depth to be certain of the quality of the ground.

It would also be desirable to show on the section the declivity of the bed of the river for a considerable distance above and below the situation of the intended bridge, and also to mark on it the velocity of the stream at different periods.

The bridge should, if possible, cross the stream at right angles; and it is an advantage, when the course of the river is nearly straight for a considerable distance above the bridge; and when there is a contraction in the channel at a little distance below it, as it renders the effects of floods less dangerous.

Water-way.

376. The water-way of a bridge should be sufficient to give free passage to the highest floods, and particular regard must be had to this circumstance in fixing the height and width between the piers.

The form and area of the water-way is often so much altered by the bulk of the piers, as to cause an increase of

velocity in the current under the bridge; and when the bottom is of such a nature that it will yield to this increased action of the current, there is much danger of the foundation of the piers being undermined; also in navigable rivers it renders the navigation difficult and often dangerous. Whereas, if the forms and dimensions of the piers be so contrived that there shall be only a very small increase of velocity under the bridge, those evils will be avoided, and the floods will pass through without doing any material injury.

Whenever the velocity is increased by contracting the width of the stream, the bottom tends to wear deeper, unless it be so hard as to resist the increased action of the current. In the latter case the chief evil will be the fall of water under the arch.

The velocity of rivers is extremely variable; it depends chiefly on the declivity of the bed, and is most considerable in mountainous countries. In level districts there is little to be apprehended from the effect of the velocity; nevertheless it would not be prudent, even in level situations, to contract the water-way so as to produce a rapid fall under the bridge, particularly if the bed of the river be not sufficiently firm to withstand it.

The danger of a considerable fall under a bridge is well known, as in the case of old London Bridge, where the fall during the ebb was generally about 4 feet; and many lives had been lost in attempting to pass it. The want of a sufficient water-way appears to have been one of the causes, if not the chief cause, of the failure of Hexham Bridge, in which the fall was not less than 5 feet at the time the bridge fell,* and the bottom not of a nature to withstand such an increase of velocity.

* Smeaton's 'Reports,' vol. iii., p. 338. It appears that the bottom was sufficient to withstand a fall of 3 feet 9 inches, but failed in the flood, which rose to 5 feet (p. 313).

Want of water-way is a fruitful source of danger to a bridge; but care should be taken not to run into the opposite extreme, as a certain amount of velocity in the current is required to prevent deposits of sand and gravel, the movement of which, in a sluggish stream, is checked by any obstacle, however slight, and which, in process of time, reduces the water-way so much as to impede the passage of floods.

377. The following Table will enable the reader to compare the firmness of bottoms of different materials. The experiments were made by Du Buat.* The second column gives the greatest velocity the material in the third column is capable of resisting; and the fourth column contains the specific gravity of the material. In the first column the popular stages of accumulation are stated.

Stages of Accumulation termed.	Velocity of River in feet per second.	Nature of the Bottom which just bears such Velocities.	Specific Gravity of the Material.
Ordinary floods	3·2	Angular stones, the size of a hen's egg	2·25
	2·17	Rounded pebbles, one inch diameter..	2·614
Uniform tenors	1·07	Gravel of the size of garden beans ..	2·545
	0·62	,, ,, peas	2·545
	0·71	Coarse yellow sand	2·36
Gliding. ..	0·351	Sand, the grains the size of aniseeds ..	2·545
Very slow ..	0·26	Brown potter's clay, mud, &c.	2·64

It is to be observed, however, that the scouring action of rivers depends also upon the *depth* or *weight* of water resting upon their beds.†

378. It appears then that the velocity of the water which should be permitted under a bridge is determined either by the nature of the bed of the river, or by the fall that would be hurtful to navigation.

* 'Principes d'Hydraulique,' tom ii., art. 399.

† Law's 'Rudiments of Civil Engineering.'

If b represent the breadth of the natural water-way, and c the breadth as reduced by the construction of the bridge; also V the velocity in feet per second of the river in its natural state: then the velocity v under the bridge will be expressed by the equation $v = m.V\frac{b}{c}$, and $c = m.b\frac{V}{v}$. Where m is a constant quantity which expresses the contraction a fluid suffers in passing through a narrow passage. According to Sir Isaac Newton's experiments, the value of m is $\frac{25}{21}$;* this value of m should be used when the ends of the piers are square. They are, however, generally made of a form better adapted for dividing the stream; some experiments were made by Du Buat with models of piers having the end facing the stream in the form of an equilateral triangle, according to which we may take $m = 1\cdot09$.† Adopting this value, $v = 1\cdot09\,V\frac{b}{c}$, and $c = 1\cdot09\,b\frac{V}{v}$.

Example.—Let the bottom of the river be fine sand, and the breadth of the natural water-way 36 feet, and the velocity $V = 0\cdot25$ foot per second. Then for a fine sandy bottom, v should not exceed $0\cdot351$ foot; hence

$$c = 1\cdot09\,b\frac{V}{v} = \frac{1\cdot09 \times 36 \times 0\cdot25}{0\cdot351} = 27\cdot7 \text{ nearly},$$

which is the breadth of the contracted water-way; and $8\cdot3$ feet may be occupied with piers without endangering the bottom.

379. Retaining the same notation, the amount of fall, h,

* 'Principles of Natural Philosophy.'

† Du Buat's lowest number is $1\cdot097$, but in wide rivers perhaps it will be less; therefore $1\cdot09$ is assumed as near the truth. See Du Buat, 'Principes d'Hydraulique.'

will be found by the equation $\frac{m^2 b^2 - c^2}{64 c^2} \times V^2 = h$.* And taking the value of $m = 1 \cdot 09$, then $m^2 = 1 \cdot 1881$; or near enough for practice, $m^2 = 1 \cdot 2$; consequently, $\frac{1 \cdot 2 b^2 - c^2}{64 c^2} \times V^2 = h$, the fall.

Example.—The breadth of the Thames above London Bridge is about 936 feet, according to the observations of Labelye in 1746; and the sum of the water-ways of the old bridge at the time of low water was about 200 feet; the mean velocity of the stream just above the bridge was $3\frac{1}{6}$ feet per second. Therefore $\frac{1 \cdot 2 b^2 - c^2}{64 c^2} \times V^2 = \frac{1 \cdot 2 \times 876996 - 40000}{64 \times 40000} \times \frac{361}{36} = \frac{1011315 \cdot 2}{2560000} \times \frac{361}{36} = 3 \cdot 96$ feet, or 4 feet nearly; which rendered the passage extremely dangerous.

The velocity of the current and the sectional area of the water-way should be ascertained at the time of the highest floods if practicable, otherwise we must be satisfied with an approximate value of the velocity at that period; which may be obtained by taking the velocity and depth at the time of observation, and assuming that the velocity during floods is increased in proportion to the square root of the depth. In a river the surface velocity in feet per second is nearly as the square root of the hydraulic mean depth multiplied by the fall in two miles, both in feet, and the mean velocity is nearly $\frac{9}{10}$ths of this quantity.

The fall under the bridge is directly as the square of the velocity, therefore there is much danger in contracting the water-way of a rapid river, and the fall will also be nearly as

* An investigation of this formula is given by Dr. Hutton in his 'Tracts;' also in his 'Course of Mathematics.'

the depth of the river; which shows how necessary it is to ascertain the height of the highest floods.*

380. The following Table, showing the velocities of some of the principal rivers, may assist in giving more accurate ideas on this interesting subject; and we have only to regret that it is not so complete as might have been expected, owing to the few observations that have been made.

Name of River.	Place of Observation.	State of River.	Velocity in feet per second.	Observer.
Thames	Above London Bridge ..	Mean state	3·1667	Labelye.
	" Westminster Bridge	Mean state	2·25	"
Seine ..	Between Tuileries and Pont-neuf	..	1·54	Marriotte.
	Between Surène and Neuilly	..	2·55	Chézy.
Tiber ..	Rome	Low water	3·28	
Danube	Ebersdoff	Low water	3·45	
		High water	from 7·2 to 12·2	
Loire ..	Declivity of the bed ·000382	..	4·25	
Rhone	At Arless	Low water	4·8	
	At Beaucaire	Low water	8·2	
Durance	From Sisternon to its mouth	Mean state	8·2	

In 1818 an immense quantity of water accumulated in the Val de Bagnes, in Switzerland, by a glacier sliding into the valley; when the ice gave way, the torrent burst forth with the tremendous velocity of 33 feet per second, and swept two bridges away in its course, and still retained a velocity of

* Respecting the velocity of rivers, and the fall of water under bridges, the reader may consult Du Buat, 'Principes d'Hydraulique,' edit. 1816; Dr. Robison's art. River, 'Encyclopædia Britannica;' Playfair's 'Outlines of Natural Philosophy;' 'Rees's Cyclopædia,' art. River, by John Farey, jun.; 'Hutton's Tracts,' vol. i.; Sir H. Douglas 'On Military Bridges;' and Dr. Brewster's 'Encyclopædia,' art. Hydrodynamics.

6 feet per second, until it flowed into the Lake of Geneva, a distance of nearly five miles.*

The Span or Width of Opening.

381. The extent of the span is the next point to be considered; it will be obvious that this is in some degree determined by what has been said respecting the area of the water-way. The span of the opening, however, must also be regulated by the form of the banks, the height of the highest floods, the depth and rapidity of the river, and the kind and dimensions of the timber that can be procured. In rivers that are tranquil, of little depth, and not subject to high and rapid floods, the number of piers may be increased without inconvenience, provided they do not interrupt the navigation of the river, nor contract too much the water-way.

But if the bridge has to cross a torrent, the fewer the number of supports placed in the stream the better. When the banks are not too low, and the width of the river does not exceed about 300 feet, the engineer whose choice is confined to a wooden bridge should give the preference to a single span or opening. For greater widths it is desirable to erect piers in the bed of the river. There is very little advantage as regards cost in adopting large spans, because in such cases the piers require to be carefully constructed, which will cause additional labour and expense.

Construction of the Abutments and Piers.

382. The abutments and piers of wooden bridges are frequently executed in stone, in which case their construction falls within the mason's province; nevertheless, as they should be capable of sustaining the thrust when curved ribs are used without a horizontal tie, the following rule is given

* 'Edinburgh Philosophical Journal,' No. 1, p. 191.

for finding the proper thickness; the abutments being rectangular, and the weight of a cubic foot of the masonry 120 lbs.

Rule.—Multiply the square of the height of the abutment by 160, and divide the product by the weight on a square foot of the arch, and by the rise of the arch; add unity to the quotient, and extract the square root.

Diminish the square root by unity, and multiply the root so diminished by half the span of the arch, and by the weight on a square foot of the arch.

Divide the last product by 120 times the height of the abutment, and the quotient will be the thickness of the abutment.

Example.—Let the height of the abutment from the base to the springing of the arch be 20 feet, half the span 100 feet, the weight of a square foot of the arch, including the greatest probable load upon it, 300 pounds, and the rise of the arch 18 feet. Then $\frac{160 \times 20 \times 20}{300 \times 18} = 11 \cdot 852$, and $11 \cdot 852 + 1 = 12 \cdot 852$. The square root of $12 \cdot 852$ is $3 \cdot 6$ nearly; and $3 \cdot 6 - 1 = 2 \cdot 6$. Also $\frac{2 \cdot 6 \times 100 \times 300}{120 \times 20} = 32 \cdot 5$ feet, the thickness required.

The thickness of the abutment thus determined is one-fourth more than would barely resist the thrust of the ribs, not reckoning the additional stability it receives from that part of the height above the springing. In order to prevent any risk of sliding at the joints of the masonry, it would be an advantage to incline them towards the opening of the bridge, making the inclination less and less as it approaches the base. In the bridge, Plate XLVIII., the joints are drawn in the manner proposed.

383. When piers are necessary, it is best to construct them of stone, as timber decays very rapidly when exposed

alternately to dryness and moisture, which is the worst situation in which timber can be placed.

Stone piers have been used for wooden bridges in many situations, particularly the following:—

Situation of Bridge.	Span of Centre Arch.		Thickness of Piers.		Thickness of Pier in parts of Span.
	ft.	in.	ft.	in.	
Bridge over the Schuylkill, at Philadelphia*	194	10	27	7	$\frac{1}{7}$
" at Trenton, over the Delaware* ..	194	0	19	0	$\frac{1}{10}$
" of Tournus, over the Saone, France†	89	6	16	6	$\frac{2}{11}$
" of Choisy, over the Seine, France† ..	67	6	9	10	$\frac{1}{7}$

It will be seen that considerable latitude has been taken in fixing the dimensions of stone piers. If it be considered that they should be capable of withstanding the thrust of the arches, their thickness should be found by the same rule as that given for the abutments. The ends of stone piers should be formed by the intersection of two parabolic curves, in order that the water may glide easily past them.‡

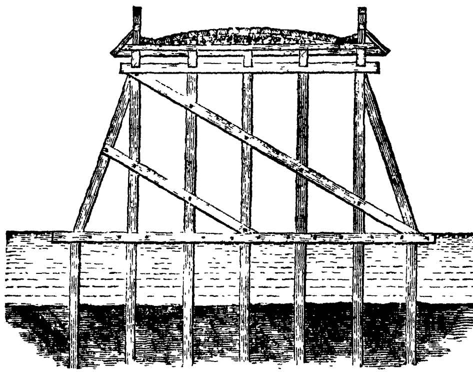
384. When piers are constructed of timber, they may, in simple cases, be formed by driving a single row of piles for each pier in a line with the current of the river. The piles may be from 10 to 14 inches square, and placed at from 2 to 4 feet distance from one another. The piles should be strengthened by oblique braces. Fig. 118 represents a pier of this kind.

385. In a deep river, or where the height of the roadway is much above the surface of the water, it is difficult to get piles of sufficient length. In such a case the piles may be driven and cut off a little below low-water mark, and upon

* 'Quarterly Review,' vol. xix., p. 256.
† Gauthey, 'Construction des Ponts.'
‡ See Du Buat, 'Principes d'I

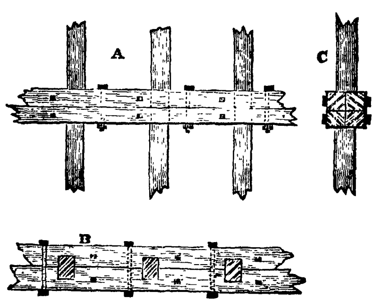
these piles posts may be placed for supporting the roadway. The joinings should be secured by means of horizontal pieces

Fig. 118.



well bolted together. A, B, and C (Fig. 119), show how the upper and lower parts of the pier should be connected.

Fig. 119.

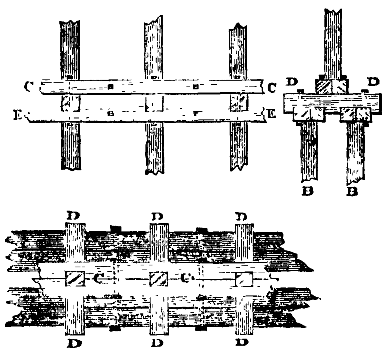


The piers of the Bridge of St. Clair, at Lyons, were con-

structed nearly in this manner,* and it has the advantage of giving a good hold to the piles, besides rendering them much easier to drive; it also cuts off the connection between the part of the pier which is constantly wet, therefore less liable to decay, and that which is alternately wet and dry, and the posts can be repaired or renewed with much greater facility.

386. When the depth of the river is very considerable, it would not be safe to trust to a single row of piles; in that case the lower part should consist of a double row, B B (Fig. 120),

FIG. 120.



at about three feet apart from middle to middle, connected by the horizontal beams E E, and the cross pieces D D, for supporting the posts.

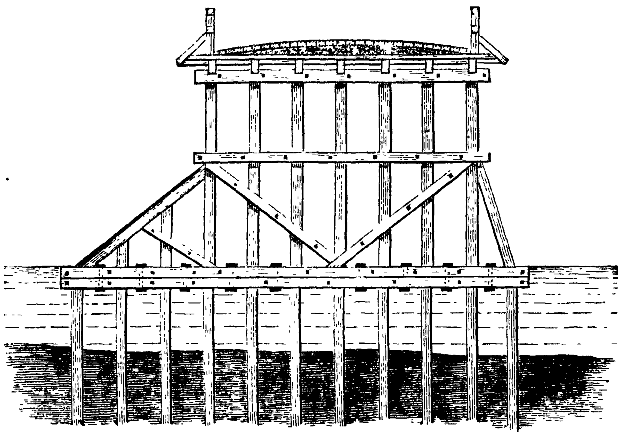
In order to secure the feet of the posts they must be clasped by two horizontal ties, C, C, and the whole well bolted together.

Figs. 118 and 121 show how the posts may be braced; and when their height is considerable, one or more courses

* Gauthey, 'Construction des Ponts.'

of horizontal ties will be required in addition to the inclined braces.

FIG. 121.



387. Instead of driving piles for the piers or supports of a wooden bridge, another method has been adopted with perfect success by Telford on the river Severn, about eight miles below Shrewsbury. He makes choice of any convenient situation on the banks of the river for constructing the pier, which consists of an upright frame, having a grated platform attached so as to form the base, which extends on each side of the upright frame. The pier is then sunk in its proper situation, the bottom having been carefully levelled to receive it.

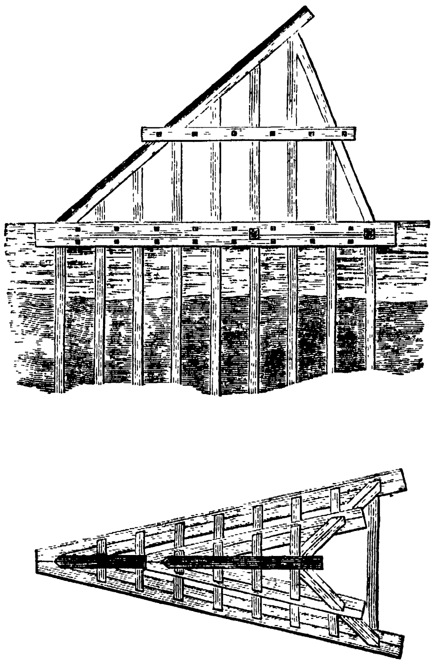
Through the spaces in the grated frame or platform short piles are driven to keep the whole secure in its place. The sides of the upright frame are covered with planking, and in order to add to the stability, the lower parts are filled with gravel and small stones.

To prevent ice, or other bodies carried down by the

current, from injuring the piers, the edges of the frames which face the stream have triangular pieces of cast iron fixed upon them.* Fender piles also are sometimes driven so as to form a triangle at a little distance above and opposite to each pier.

388. When a river is subject to ice floods the piers should

FIG. 122



be protected by ice-breakers, which should be detached, in order that the bridge may not be injured by the shock of bodies descending with the current. Ice-breakers may con-

* 'Edinburgh Encyclopædia,' art. Bridge.

sist of a single row of piles, connected by two horizontal beams, with an inclined capping, the edge of which is protected by a triangular prism of cast iron, or it may consist of two rows of inclined piles, the heads of which abut against an inclined capping, protected with iron as shown by Figs. 122 and 123. The inclined sides ought to be covered with planking, though not shown in Fig. 122.

In a large bridge there is little danger to be apprehended from connecting the ice-breaker with the pier.

389. Piles from 10 to 14 inches diameter require to be driven with a ram of from 1000 to 1700 lbs. weight.

Sheeting piles require a ram from 500 to 900 lbs. weight, and are about 8 or 9 inches wide and 3 or 4 inches thick.

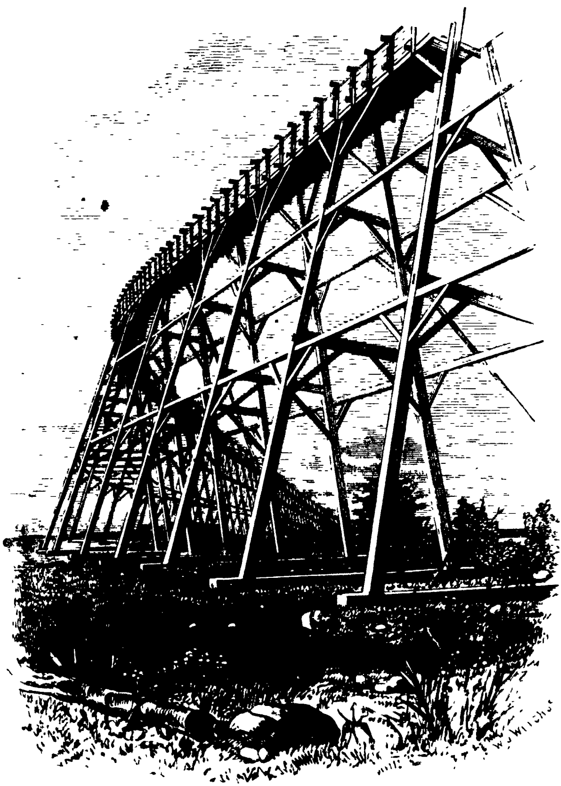
Notwithstanding that every precaution is taken to ensure the durability of wooden piers, they are almost always found to be in a state of decay before the superior parts of the bridge; therefore wood should only be used when stone is difficult to procure.

390. In situations where timber is liable to be attacked by the worm, iron piles might be used with advantage, and where the soil is soft or sandy, the screw-pile invented by Mr. Alexander Mitchell is one of the best that could be devised; even in ordinary situations, a cast-iron screw may be used to form the base of the wood pile which is to support the bridge. The screw to have a socket end to project above the ground into which the foot of the wood pile can be stepped.

391. Fig. 89, Art. 287, and Figs. 112 and 117, Art. 344, show the methods of framing applicable to the piers of viaducts and aqueducts, which are usually of great height. Fig. 124 shows the method adopted in framing the trestles or supports of a lofty aqueduct near Smartsville, Yuba County, in California, described by Mr. J. A. Phillips in

his work on the 'Mining and Metallurgy of Gold and Silver.'

FIG. 124.



ROADWAY.

392. The roadway of the bridge should be kept as low as may be consistent with the requirements of the navigation and water-way. The ascent on each side should be as easy

as the circumstances will admit of, and in no case should it exceed 1 part in 12.

Smeaton remarks of old Westminster Bridge that the ascent was originally laid out to be 1 part in 20, but he apprehends it to be at least 1 in 12; and further observes that it is a kind of rule in laying out roads and bridges, "if the ascents do not exceed 3 inches per yard, they are no ways objectionable." *

Holborn Hill, before the erection of the Viaduct, is stated to have had a rise of 1 in 18, and that it was necessary at all times to lock the wheel of a loaded waggon. Ludgate Hill rises only 1 in 36; † and when it is possible to construct a bridge with so gentle a rise it is much more desirable. Telford mentions 1 in 24 as a convenient ascent for a bridge; ‡ Wiebeking § also names a rise of 1 in 24 as that which may be used without inconvenience; but he observes that in timber bridges the settlement is generally about 1 part in 72; that is, if a timber bridge of 144 feet span rise one foot in the middle when first framed, it will settle so as to become nearly horizontal; therefore, when it is intended that the bridge shall have an ascent of 1 in 24 when finished, it must be framed so as to have a rise of 1 in 18; for $\frac{1}{18} = \frac{1}{24} + \frac{1}{72}$.

393. The width of a bridge depends wholly on the situation where it is to be erected. It ought to be wide in proportion to the importance of the communication, and according to the population who are likely to use it; but the width should not be greater than necessary, because it increases the expense of erection without adding to the utility.

The width between the parapets of a bridge intended for

* Smeaton's 'Reports,' vol. iii., p. 226.

† 'Ency. Brit.,' art. Bridge.

‡ 'Edinburgh Ency.,' art. Bridge.

§ 'Traité d'une Partie essentielle, &c.,' p. 125.

wheeled carriages may be from 18* to 50 feet, according to the situation. Where the road is at a distance from any principal town, and the traffic is slight, the width of the bridge may be from 18 to 20 feet: in more frequented places, from 20 to 22 feet. Near towns and on great public roads, from 25 to 30 feet, and in or near large cities from 30 to 50 feet.

In private roads and parks they are made from 12 to 20 feet in width, and foot bridges from 5 to 8 feet.

394. The roadways of bridges are formed in various ways; one of the most usual is to use pitcher paving laid upon gravel; sometimes broken stone or gravel is used, and some prefer sheeting or planking with timber.

The planking in small bridges is often laid immediately upon the principal beams, which, in such cases, are placed about 2 feet apart, as in Fig. 118, but it is better as regards durability to lay cross joisting for supporting the planking; these joists should also be about 2 feet apart, and the planking laid upon them, which may be from 3 to 4 inches thick. The cross joists admit the air to circulate more freely round the principal timbers, which renders them less likely to decay.

Where bridges are intended for wheel carriages there should be a separate footpath, which may be paved with flagstones. Footpaths are made from 3 feet to 6 feet wide according to the number of the passengers. The carriageway may be paved upon a bed of gravel of about 12 inches in depth. The paving to rise in a curve across the road. The gravel should contain a considerable portion of tempered clay, so as to bind it firmly together; but if there be too much clay, it will shrink and crack in drying. Belidor states, that paved bridges are the most durable.

* Smeaton says that it is found by experience that 18 feet clear width admits of carriages passing with ease, freedom, and safety ('Reports,' vol. iii., p. 51).

If the roadway be gravelled only, the gravel should be from 12 to 18 inches deep in the middle and from 9 to 14 inches deep at the sides, according to the traffic over the bridge. Whether the roadway be paved or gravelled, the means of conveying off the water should be provided.

As the moisture which passes through the gravel soon rots the planking, it is supposed to be better to lay an additional thickness of planking, and no gravel or paving. In that case the upper planking should lay across the bridge, to prevent the feet of horses from slipping. It would be easy to renew such a roadway, but it is not clear that it possesses any other advantage.

Parapets or balustrades are made from 3·5 feet to 6 feet in height above the footpath; 4 feet is enough for protection. The railing is stayed by braces on the outside. Iron-railing is sometimes used.

The railing should, however, partake of the character of the surrounding scenery. In towns, upright or diagonal bars and other ornamental railing may be used; but in all cases where trees and cottages form the most striking features of the surrounding landscape, simple horizontal rails with posts are preferable. Nothing is more formal and stiff than ornamental or upright railing, and nothing more picturesque than the simple continuous lines of horizontal rails.

Wooden bridges are often covered with a roof. The bridges of Schaffhausen, Wettingen, Kandel, Mellingen, and various others were roofed. The roof does not appear to be of much service in protecting the bridge, and in later bridges it has been generally omitted. The planking of the roadway might be protected very much by a coat of pitch, tar, and sand. A composition of this kind was used for covering the planking under the roadway of the iron bridge over the Wear, at Sunderland.

SECTION XI.

JOINTS, STRAPS, AND OTHER FASTENINGS.

395. The joints in a framing of timber having to resist the strains to which the pieces are exposed, should be formed in such a manner that the bearing parts may have the greatest possible amount of effective surface. For should that part of the joint which receives the strain be narrow and thin, it will either indent itself into the pieces to which it is joined, or become crippled by the strain; producing in either case a change in the form of the framing.

The effect of the shrinkage and expansion of timber should also be considered in the construction of joints. On account of the shrinkage of timber, dovetail joints should seldom be used in carpentry, as the smallest degree of shrinking allows the joint to draw out of its place; they can only be used with success when the shrinkage of the parts counteract each other; a case which seldom happens in carpentry, though common in joinery and cabinet-making.

Joints should also be formed so that the contraction or expansion may not have a tendency to split any part of the framing. The force of contraction or expansion is capable of producing astonishing effects where the pieces are confined, which may sometimes be observed where framing has been wedged too tightly together in improper directions. The powerful effect of expanding timber is well known to quarry-men, as they sometimes employ its force to break up large stones.

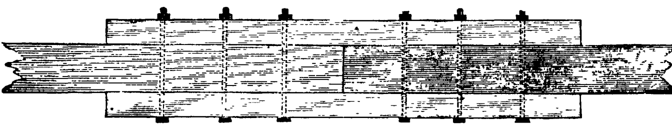
396. In forming joints the object to be attained should

always be kept in view, as that which is excellent for one purpose may be the worst possible for another. With this consideration the subject will be treated under separate headings, as follows:—

Lengthening Ties.

397. The simplest and perhaps the best method of lengthening a beam is to abut the ends together, and place a piece on each side; these, when firmly bolted together, form a strong and simple connection. Such a method of lengthening a tie is shown by Fig. 125, and is what ship-carpenters call

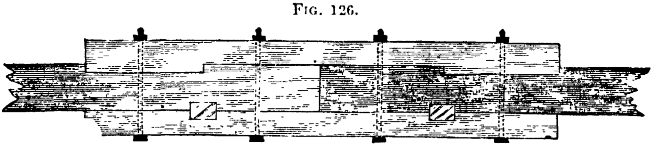
Fig. 125.



fishing a beam. It is obvious, however, that the strength in this case depends on the bolts, and the lateral adhesion and friction produced by screwing the parts tightly together.

The dependence on the bolts may be lessened by indenting the parts together, as shown by the upper side of Fig. 126;

Fig. 126.



or by putting keys in the joint, as shown by the lower side of the same figure; but the strength of the beam will be decreased in proportion to the depth of the indents.

The only reasons for not depending wholly on bolts are,

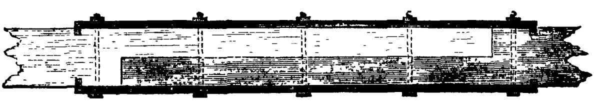
that should the parts shrink ever so little, the bolts lose a great part of their effect; and the smallness of the bolts renders them liable to press into the timber, and thus to suffer the joint to yield.

The sum of the areas of the bolts should never be less than one-fifth of the area of the section of the beam; and they should not be placed too near to the ends of the pieces.

398. The most usual method of joining beams is that called *scarfing*, where the two pieces are joined so as to preserve the same breadth and depth throughout; and wherever neatness is preferable to strength, this method should be adopted.

From Fig. 127 to Fig. 134 various methods of scarfing are shown. The first (Fig. 127) is the most simple; it de-

FIG. 127.



pends wholly on the bolts, and in this and like cases it is best to put a continued plate of iron on each side to receive the heads of the bolts. The ends of the plates may be bent and let into the beams.

399. Fig. 128 is another very common, but not so good a combination, as the bolts do not press the surfaces in a

FIG. 128.

perpendicular direction: and an oblique pressure, such as would be likely to take place in this example, must have

some tendency to separate the joint, and it has no advantage in other respects.

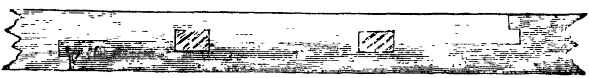
400. Fig. 129 is a joint where bolts would not be absolutely required, but it is clear that the strength would not

FIG. 129.

be quite so great as half that of an entire piece; the key, or double wedge in the centre of the joint, should only be driven so as to bring the parts to their proper bearing, as it would be better to omit it altogether than to drive it so as to produce any considerable strain on the joint. It is not necessary that there should be a key, except when bolts are to be added, and then it is desirable to bring the joints to a bearing before the bolts are put in. The addition of bolts and straps, however, makes this an excellent scarf.

401. Fig. 130 is a slight modification of the last, where the keys are supposed to be of hard wood; if of a curled

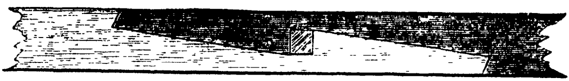
FIG. 130.



grain, so much the better. In this form the scarf is easier to execute, and equally as good, when bolts are used, as that shown by Fig. 129.

402. Fig. 131 represents a good and very common form,

FIG. 131.



though inferior to the two preceding ones (Figs. 129 and

130), and it is much more difficult to make with it a sound joint.

When bolts are added, and they are always necessary in pieces exposed to considerable strains, then the form represented by Fig. 132 becomes a very good and strong scarf.

FIG. 132.

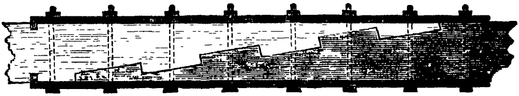
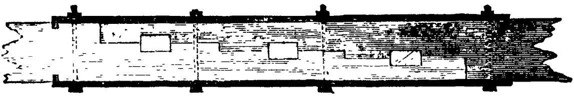


Fig. 133 differs from the last only in having keys instead of being tabled together.

FIG. 133.

403. Fig. 134 represents a scarf where the oblique joints in the last examples are avoided, and the same degree of

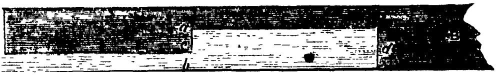
FIG. 134



strength is obtained; it is at the same time very simple, and easy to execute.

404. To determine the length of a scarf, in joining beams, it is necessary to know the force that will cause the fibres of

FIG. 135



timber to slide upon each other. Some information on the

subject has been already laid before the reader in Sect. II., Arts. 133 and 134. To apply it to our present object, let A B, Fig. 135, be part of a scarfed beam, strained in the direction of its length, and put together without bolts. Now it is plain that the strength of the part *c b* must be exactly equal to the force that would cause the fibres to slide at the dotted line *c d*; for if the part *c d* were shorter, the joint would not be so strong as it is possible to make it. Also, if the depth of the indent *a c* be too small, it would be crushed by the strain; consequently the parts must have a certain proportion, so that the joint may be equally strong in every part.

405. Where the amount of extension and compression is very small, the resistance may be considered as equal, therefore the depth of the indent *a c* must be equal to the part *c b*, in order that the strain may be equal; and it is evident, that when there is only one indent, as in this example, the depth *a c* should be one-third of the whole depth. Also let *d* be the depth of the beam, and *m* the number of indents; then $\frac{d}{3m}$ = the depth of each indent. Or the sum of the depths of the indents must be equal to *one-third* of the depth of the beam.

406. To determine the length of the part *c d*, we must know the ratio between the force to resist sliding and the direct cohesion of the material. Let that ratio be as 1 : *n*; then *c d* must be equal *n* times *c b*; that is, in oak, ash, or elm, *c d* must be equal to from 8 to 10 times *c b*.

In fir and other straight-grained woods, *c d* must be equal to from 16 to 20 times *c b*.

407. Hence may be derived some maxims that will be sufficiently accurate for practical purposes:

1. In oak, ash, or elm, the whole length of the scarf should be *six times* the depth or thickness of the beam, when there are no bolts.

2. In fir the whole length of the scarf should be about *twelve times* the thickness of the beam, when there are no bolts.

3. In oak, ash, or elm, the whole length of a scarf depending on bolts only, should be about *three times* the breadth of the beam; and for fir beams it should be *six times* the breadth.

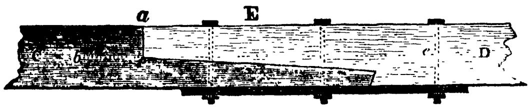
4. When both bolts and indents are combined, the whole length of the scarf for oak and hard wood may be *twice* the depth; and for fir or soft woods, *four times* the depth.

Lengthening Beams to resist Cross Strains.

408. Beams to resist cross strains require to be lengthened more frequently than any others, and, from the nature of the strain, a different form must be adopted for the scarf from that which is best for a strain in the direction of the length. There are cases where beams are exposed to both strains at the same time, but the cross strain is generally that of the most importance. Of this we have an example in the tie-beam of a roof, where the strain in the direction of the length is very small compared with the cross strain.

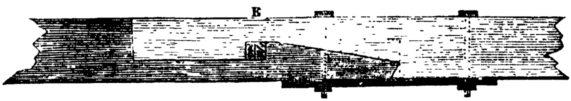
Let C D, Fig. 136, represent a beam strained by a load at E, and supported at the ends. All the parts above the middle of the depth, $b\,c$, will be compressed, while those

Fig. 136



below will be extended; therefore, the square abutment $a\,e$ is better for the upper side than any kind of complicated joint; and it is evident that all oblique joints should be avoided on

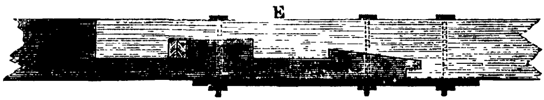
Fig. 137.



It will readily appear that had the joint been cut to the dotted line instead of the oblique line, the strength would have been much impaired.

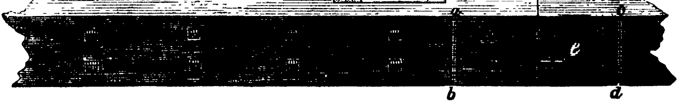
Fig. 138 is another form with some slight alterations.

Fig. 138.



410. Fig. 139 represents an angular view of a scarf where it is jointed the contrary way. An iron plate at *a b c d* is

Fig. 139.



supposed to be removed, which shows the tongue at *e*. This method appears to employ more of the strength of the timber than any other, and is very well adapted for a tie-beam

where it is strained both across and in the direction of its length.

In all these cases the depth of the indents and the length of the scarf will be obtained by the same rules as for beams strained in the direction of their length (see Arts. 405 to 407).

In scarfing beams to bear a cross strain it would be a great advantage to apply hoops or straps instead of bolts, as the coachmakers and ship-carpenters do. It would be easy to form the scarf so that hoops might be driven on perfectly tight.

There is no part of carpentry that requires greater accuracy in workmanship than scarfing; as all the indents should bear equally, otherwise the greater part of the strength will be lost. Hence we see how very unfit some of the complicated forms shown in the old works on carpentry were for the purpose. It is certainly very absurd to render the parts difficult to be fitted, when the whole of the strength depends on their fitting well. "But many," says Professor Robison, "seem to aim at making the beam stronger than if it were of one piece; and this inconsiderate project has given rise to many whimsical modes of tabling and scarfing." *

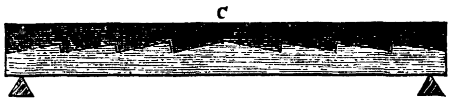
Building Beams.

411. The method of building beams has already been considered in Section III., Arts. 203 to 206. It may not however be superfluous here to remark, that the position of the indents is not a matter of indifference. If two plain pieces were laid upon one another, and supported at the ends, the pressure of a weight applied in the middle would cause them to bend, and the surfaces in contact would slide against one another, the upper piece sliding towards each end upon

* Art. Carpentry, 'Encyclopædia Britannica.'

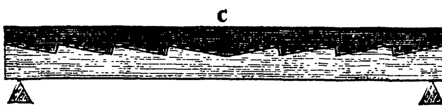
the lower one. This sliding is effectually prevented by indenting the surfaces, as shown in Fig. 140, when the pieces are bolted together; but if the same indents be

FIG. 140.



reversed, as in Fig. 141, they produce scarcely any effect, and nearly the whole strain is upon the bolts.

FIG. 141.



Wherever the principal strain on the beam may happen to be, to that point, as at C, Fig. 140, the indents should direct their square abutments; that is, towards the straining force. When the beam is uniformly loaded, the greatest strain is at the middle.

In drawings we frequently see all the indents put the same way, and sometimes as in Fig. 141, otherwise the preceding remarks would have appeared to have been unnecessary.

If the depth of the indents be too small in a built beam, they will not be capable of resisting the pressure; and if they be made too deep, the number of fibres will be diminished, and consequently the strength of the beam; therefore, there is a depth for the indents, by which a maximum of strength will be gained. Duhamel undertook to ascertain the proper depth by experiments;* and the general rule, given in Art. 205, Sect. III., agrees tolerably well with the case he tried.

‘Transport des Bois,’ p. 498.

Lengthening Beams to resist Compression.

412. When a post or strut is required to be longer than timber can be procured, which sometimes may occur, the same form of joint or scarf is applicable as when the piece is pulled in the direction of its length, with this difference, that there must not be any inclined or oblique parts in the scarf.

Figs. 127, 129, 130, 134, 135, and 139, will answer equally well for posts or ties, except that it would be better to tongue the ends as at *e*, Fig. 139.

In Fig. 125 a piece on each of the four sides would be necessary, unless some other mode of strengthening it could be applied in the arrangement of the framing. It is not a very neat method of splicing a strut, but it is a very convenient one, especially in temporary structures, such as centres, where it may generally be braced in one direction, and where a more elaborate form of joining would be out of place.

Joints of Bearing Timbers and Framing.

413. *Joints of Bearing Timbers.*—The connection of a binding joist to a girder is an example of this kind of joint. The greatest strains upon the fibres of a girder are at the upper and lower surfaces, and they gradually decrease towards the middle of the depth, where they become neutral; hence the most suitable place for a mortise is at the middle of the depth.

To find in what proportion a beam is weakened by a plain rectangular mortise cut in the middle of the depth, let D be the depth, and B the breadth of the beam, D′ the depth of the mortise, and B′ the distance to which it penetrates

into the beam; then the beam is weakened in the following ratio:*—

$$BD^3 - B'D'^3 : BD^3.$$

The upper side being compressed, it is imagined by some writers that the tenon might be made to fill the mortise so completely that the strength of the girder would not be impaired by it, but this is a mistake; for any one who understands the practice of carpentry, knows that it cannot be done in an effectual manner: besides, the shrinkage of the joist would soon render it loose, however tightly it might be fitted in the first instance.

Assuming then the best place for a mortise in a girder, or other beam in a like position, is at the middle of its depth, the next point to consider is the best form and place for the tenon.

If the tenon were to be placed near the lower side of the joist, it would obviously be in the strongest position; but as the mortise would also have to be cut near the lower side of the girder, this cannot be adopted; therefore the form in general use, and that which appears to combine most of the advantages, is represented by Fig. 72, Art. 211, which is called a "shouldered tenon," the tenon being one-sixth of the depth of the joist, and placed at one-third of the depth from the lower side. The shoulder *b* should penetrate the side of the girder also about one-sixth of the depth. The length of the tenon beyond the shoulder should be about double its own depth. An iron screw, called a "bed-screw," is often used to secure a joint of this kind.

414. Binding joists, or any other beams in a like position, should never be made with double tenons; for, as Price has judiciously remarked, it weakens the timber into which it is framed, and both tenons seldom have a bearing at the same

* Rankine, 'Engineering,' 1869.

time; besides, it rarely happens that they can be pinned so that both may draw alike, unless the pin be as tough as wire.*

All horizontal timbers for bearing purposes should be notched upon the supports rather than framed between, whenever it can be done, and much additional strength is gained by keeping timbers in continued lengths. The same observation applies to inclined timbers, such as common rafters (see Sect. II., Art. 107).

415. *Joints of Framing.*—The object to be obtained by a system of framing is to reduce all the pressures into the directions of the lengths of the pieces composing the frame; therefore the form of the joint should be made so as to direct the pressures into the axes of the pieces. As when the direction of the strain does not coincide with the axis of the piece, the strain will be much increased. Now, from the form of the joints commonly employed, it must generally happen, that by shrinkage, or settlement, the joints will bear only upon the angular points of the shoulders; which not only gives a considerable leverage to the straining force, but also, in consequence of the whole bearing being upon an angle, the piece must be either indented or crippled by the strain, which would of course cause a further settlement. The extent of the evil arising from partial bearings becomes very manifest when the strains are considerable. In the centres of the Bridge of Neuilly seven or eight pieces in each frame were split from end to end, and many others were bent considerably. The joints were not what would be called very oblique, otherwise the effects might have been more serious. Perronet was aware of the cause, and in order to correct it, he formed the abutments according to an arc of a circle, of which the other extremity of the piece was the centre.

This method was adopted for the joints of the centre for

* 'British Carpenter,' Introduction.

the Bridge of Sainte Maxence, and also in that for the Bridge de la Concorde, at Paris; and it was effectual in preventing the splitting and bending of the pieces.*

Circular abutments have been strongly recommended by Professor Robison,† and they certainly might be employed in many cases with advantage. The principle is similar to the well-known contrivance called the ball and socket; and to the joints of animals, where, with considerable latitude of motion, uniformity of pressure is preserved. They require more labour, but that would be a comparatively trifling object in a framing of importance.

It is obvious, that when motion takes place in the opposite end of the piece, a corresponding movement will take place at the joint, and when the radius of curvature at the joint is small, the motion there will scarcely be perceptible. For in a roof of 30 feet span a sinking of six inches in the middle would not cause the joints to slide more than one-tenth of an inch.

We will now proceed to describe some of the joints of most common occurrence, and endeavour to point out improvements that might be made in some of them.

When one piece is perpendicular to another, as, for example, a post upon a sill, the usual, as well as the most easy method, is to make the joint square, with a "stub" or short tenon of about one-fourth of the thickness of the framing, to retain it in its place.

But if the joint be not very accurately cut, the whole load will bear upon the projecting parts; consequently, the centre of pressure will seldom coincide with the axis of the post, and its power of resistance will be much lessened.

If, instead of cutting the joint square, it were cut to form

* Gauthey, 'Construction des Ponts.'

† In the 'Encyclopædia Britannica,' art. Carpentry, and 'Parliamentary Report on the Improvement of the Port of London.'

an angle, as shown by Fig. 142, then a very little care in cutting the joint would make the centre of pressure coincide with the axis.

416. Now whether the joint be square or angular, a slight inclination from the perpendicular will throw the pressure

FIG. 142.

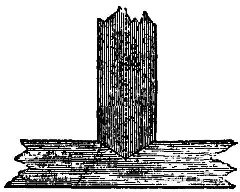
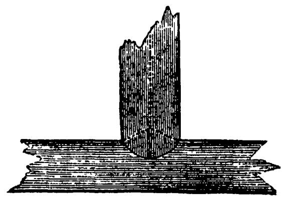


FIG. 143.



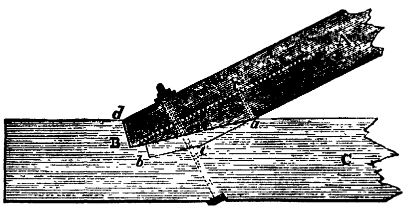
upon one corner; but if the joint be described from a centre situate in the axis, and with a radius not much greater than half the breadth of the post, as shown in Fig. 143, then, with any change of position, the joint will slide till the pressure is uniform; and if the joint be moderately well made, the pressure will not act with any sensible leverage upon the post. But if the post be of any considerable length, a rounded end is not so strong to resist compression as a square one, particularly if the latter be fixed (see Sect. II., Art. 152).

417. When the pieces to be joined are not at right angles to one another, the joints may be similar to those used for the principal rafter of a roof. But before we proceed to describe these joints, it is necessary to state that the direction of the strains, as well as their magnitude, remain sensibly the same, whatever may be the form of the abutting joints, except so far as the form of the joint alters the points of bearing; which may in some cases cause the pressure to act with a leverage nearly equal to half the depth of the beam. The strength of the joint itself depends upon its form, as it may be so made that there will be a tendency to slide, which it would be well to avoid, without having recourse to straps.

The resistance at the joint is always most effectual when the abutment is perpendicular to the strain, but where the angle formed by the inner sides of the pieces is very acute, this kind of abutment cannot be obtained, at least not without wounding the tie too much.

Let A B C, Fig. 144, be the joint of a principal rafter upon the tie-beam; where the dotted line A B shows the direction

FIG. 144.

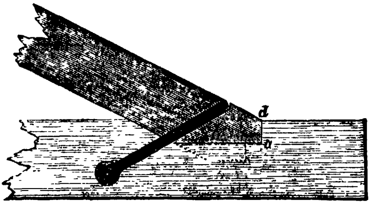


of the straining force, and B *a* is one of the abutting surfaces. Draw *a c* perpendicular to B *a*; then, by the principles of the resolution of forces (Sect. I., Art. 28) *c a* will represent the force pressing on the inclined part, B *a*, of the joint; and there will remain a force represented by B *a* to be sustained by the abutment B*d*. And as this abutment will resist the force most effectually when it is perpendicular to it, therefore B *d* should always be perpendicular to B*a*; the same will be true in whatever direction the straining force acts.

Fig. 144 shows one of the best and most common forms of joint; B*a* and B*d* are the abutting surfaces, which are to be perpendicular to each other; and *b c* shows the tenon, the thickness of which may be about one-fifth of that of the framing. This joint might always take a better hold of the tie-beam than it is generally made to do, without any risk of weakening it. In general, B *d* should somewhat exceed half the depth of the rafter, and the joint should be left a little open at *a*, in order that it may not be thrown off at B, by the settling of the roof.

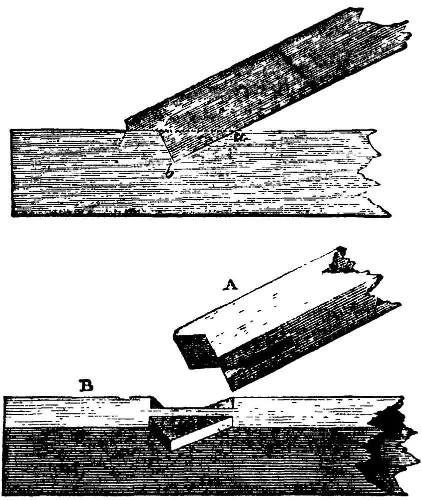
418. Fig. 145 is a form that is approved by some writers, but by others it is considered inferior to the one already

FIG. 145.



described. The dotted line shows the form of the tenon; but it would be better put together in the same manner as the joint to be described in the next article.

FIG. 146.

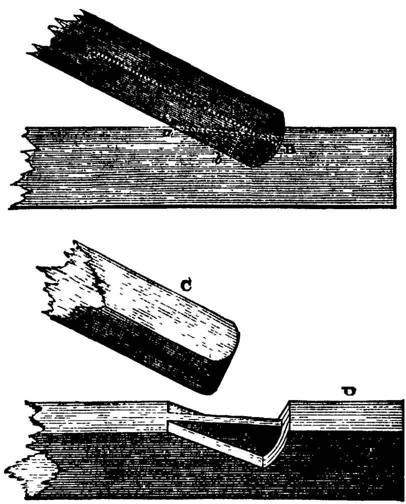


419. Fig. 146 is a very good form for a joint, as $o\,d$ is perpendicular to the strain, considering the strain to be in the

direction of the rafter, which is near enough to the truth for our present purpose. The best method of forming this joint is shown by the projected sketches A and B; as by this method it is easy to see when they are accurately fitted; whereas in a mortise-and-tenon joint this cannot be done, because it is easy to conceal any defect. Care should be taken, however, to prevent the pressure from coming on the upper part at *d*, which would be liable to split off.

420. Fig. 147 shows a joint with a curved abutment; the line B A represents the direction of the strain; and *c* the

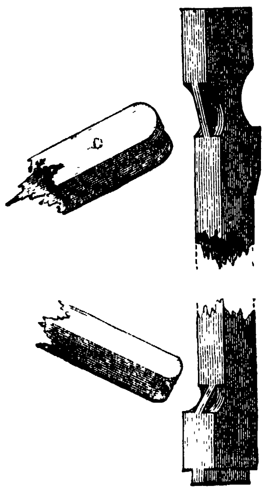
FIG. 147.



centre, which should be in this line. The radius for describing the joint should be greater than half the depth of the rafter; and the part between *a* and *b* of the joint should be left open to admit of any settlement that may take place. The projected sketches, C and D, show the manner of forming the joint.

Sometimes double abutments are used in joints, but they require great accuracy in workmanship, and also that the roof should not settle more nor less than the workman has allowed for, in order that both may have an equal bearing. For this reason one good abutment is preferable to two.

FIG. 148.



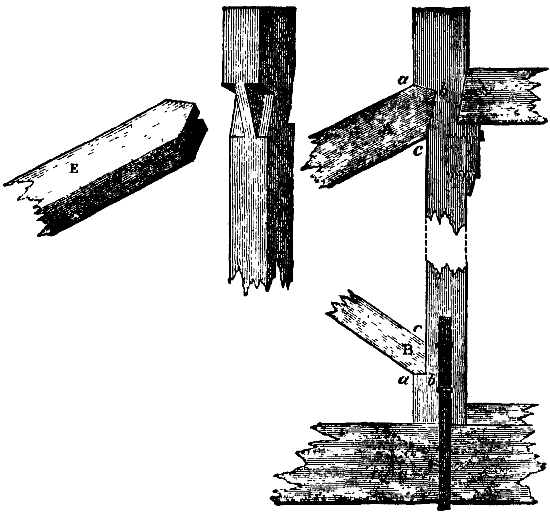
Professor Robison very justly remarks, that "because great logs are moved with difficulty, it is very troublesome to try the joints frequently to see how the parts fit; therefore we must expect less accuracy in the interior parts. This should make us prefer those joints whose efficacy depends chiefly on the visible joint."* But double abutments still further increase the difficulty, without adding anything to the security of the joint.

421. The joint at the upper end of a principal rafter differs from that at the lower end in some respects; but the dif-

* 'Encyclopædia Britannica,' art. Carpentry.

ference is not material as regards the principle of forming the joint. Making the king post larger at the head enables us to get a more effectual abutment; and this abutment in common joints should be square to the back of the rafter, as at A, in Fig. 81, Art. 250, with a short tenon as shown by the dotted lines. When the head of the post is not sufficiently large to get the abutment square to the back of the rafter, it

FIG. 149



is usual to cut it as at B. In either case the joint should be left a little open at *a*; so that when the roof settles it may not bear upon the acute angle.

The same remarks will apply to all similar joints; such, for example, as the joints between the braces or struts and king post at C and D, Fig. 81, Art. 250.

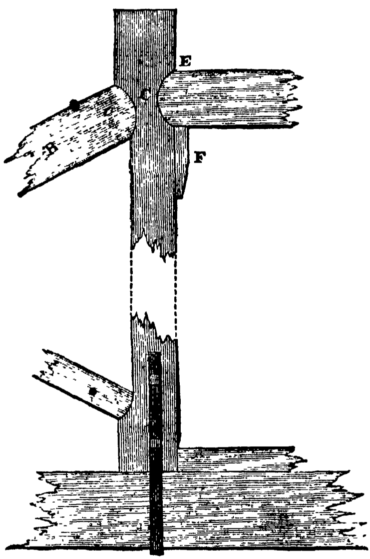
But the joints D and B would be better formed in the manner shown at A and B, Fig. 149, where *a b* is at right

angles to *b c*. The reason for this form is given in Art. 419. The joints may be made as shown by the projected sketches E and F.

422. A joint with a curved abutment is shown by Fig. 150; B C represents the middle of the depth of the rafter, and *c* the centre from which the curve is described; the radius C *c* should not be less than half the depth of the beam. A and D, Fig. 148, are projected sketches of the joint.

In Fig. 150, E shows a joint for the straining beam of

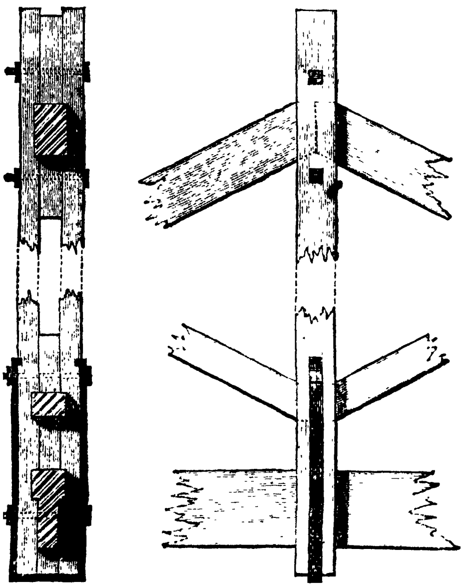
FIG. 150.



a roof, and G, Fig. 148, is a projected sketch of the joint. As a further security, the piece F might be nailed upon the queen post C. The lower part of Figs. 148 and 150 show the joints for struts or braces.

423. Instead of the common method of framing the king or queen posts between the ends of rafters and the like, it is much better to make the rafters abut against one another, end to end; and to notch a piece on each side, and to bolt through them as stated in Art. 254. Fig. 82, Art. 254, and Fig. 151 show this method of joining, which has been long used for centres, bridges, and roofs.*

FIG. 151.



The German carpenters put a piece of lead between the abutting surfaces of their joints, in order to equalize the pressure. This precaution is not, however, so necessary in timber-work as it is in stone-work; a plate of cast iron between the surfaces would be more useful.

* Rondelet, 'L'Art de Bâtir.'

Joints for Ties and Braces.

424. There is no part of carpentry where defective joints are attended with such serious consequences as in ties, nor are there any other joints so often ill constructed. It is not easy to make a good tie-joint, from the very nature of timber, and therefore it is always desirable to avoid the use of wooden ties. Where they cannot be prepared in one piece the maxim cannot be too strongly urged, as we have stated in Art. 395, "that dovetail joints should seldom be used in carpentry," and never when the joint is intended to hold the parts together.

For let A, Fig. 152, represent the angle of a building, where the wall plates are joined by a dovetail joint; the part *a b* being the crossway of the wood, will shrink in drying; and as the other piece is the lengthway, its shrinking will be

Fig. 152.

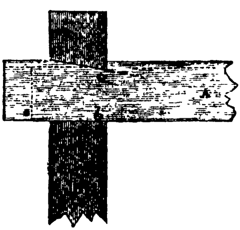
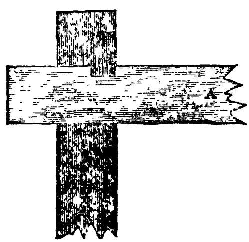


Fig. 153.



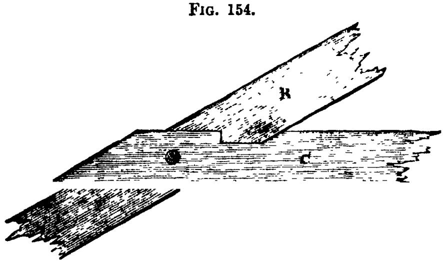
insensible; therefore a very small degree of shrinkage will allow the joint to draw considerably, as shown by the dotted lines, and it acts with the power of a wedge to force off the end of the piece. A joint made as shown in Fig. 153 avoids any danger of giving way from the shrinking of the timber, and is better than any dovetail joint whatever.

Dovetail joints, or dovetail tenons, have been used in

various parts of carpentry; such as the collar-beams of small roofs, the lower end of king and queen posts, and for joining plates, and the like. In all these cases they are the worst kind of joints that can be used. The carpenter's boast, as described in Nicholson's 'Carpenter's Guide,' must also be classed as a dovetail joint, and equally defective.

425. Fig. 154 shows a method of notching a collar-beam, C, into the side of a rafter R, which is far superior to a

FIG. 154.



dovetail joint, though also defective, owing to the manner the rafter is weakened by being cut into.

A stout pin, of tough but straight-grained oak, is an excellent addition to a tie-joint, and is more economical, where numbers are required, than an iron bolt, though, of course, not so strong. The excellence of wooden pins is fully shown by their extensive use in ship carpentry, where they frequently form the chief connection of ship timbers (see Art. 135, Sect. II.).

STRAPS, BOLTS, AND OTHER FASTENINGS.

426. The iron used in straps and bolts should be of a quality tough and fibrous, so as not to be liable to snap with any sudden application of a strain which would otherwise be within its strength.

Mr. Kirkaldy* has shown that the mere weight which destroys the cohesive force of iron does not indicate its quality. A high breaking strain may be due to the material being of superior quality, dense, fine, and moderately soft; or simply to its being very hard and unyielding. A low breaking strain, on the other hand, may be due to looseness and coarseness in the texture; or to extreme softness, although very close and fine in quality.

427. Fibrous iron elongates considerably under heavy strains; and when it breaks, the fractured part is much reduced in section, frequently in good iron to the extent of 30 or 40 per cent. In iron of inferior quality the area of the section at the point of fracture is scarcely reduced at all.

By careless forging, the best iron may be seriously injured, and give results little superior to those of the worst. Owing to uncertainty in the strength of inferior iron, it is more economical to use only such as may be of good quality, as it can be submitted with safety to a much greater load.

In proving iron (and all iron should be submitted to proof before it is used in important structures) it should not be subjected to a greater strain than *one-half* of that which would produce fracture, as a greater strain would injure the elasticity of the iron, and it would no longer be capable of resisting the sudden application of a heavy load. The greatest *safe* load to which iron should be permanently submitted is *one-fourth* of its nominal breaking weight.

428. The cohesive strength of different kinds of iron and steel is shown in the following Table, which will be of service in finding the dimensions of straps, &c.

* 'Experiments on Wrought Iron and Steel.'

Description.	Breaking Weight of a Square Inch.				Authority
	Highest.	Lowest.	Mean.		
	lbs.	lbs.	lbs.	tons.	
Iron wire	96,096	79,968	86,016	38¼	Telford.
,, ...	..	..	74,478	33¼	Daglish.
English iron ..	..	..	61,600	27½	Telford.
,, ...	..	..	55,772	25	Rennie.
Welsh iron	..	..	64,960	29	Telford.
,, ...	..	..	55,776	25	Brown.
Iron bars, rolled ..	68,848	44,584	57,555	25¾	Kirkaldy.
Angle iron, &c. ..	63,715	37,909	54,729	24½	,,
Iron plates, lengthways	62,544	37,474	50,737	22¾	,,
Iron plates, crossways	60,756	32,450	46,170	20½	,,
Swedish iron ..	..	..	78,850	35¼	Muschenbrock.
,, ...	..	..	64,960	29	Telford.
,, ...	..	..	53,244	23¾	Brown.
,, hammered bars	55,829	41,034	46,297	20¾	Kirkaldy.
German iron ..	..	..	69,133	31	Muschenbrock.
French iron	..	..	61,041	27¼	Perronet.
Russian iron ..	..	..	59,472	26½	Brown.
Steel bars	148,294	42,564	98,329	44	Kirkaldy
,, plates	108,906	62,435	86,166	38½	,,
Cast iron	..	..	19,488	8¾	Rennie.
,, ...	25,764	12,694	16,330	7¼	Hodgkinson.
,, Welsh ..	..	..	16,255	7¼	Brown.

429. The resistance of wrought iron to a shearing force equals $\frac{5}{6}$ths of the cohesive strength of the section sheared.

430. "A skilful carpenter," says Professor Robison, "never employs many straps, considering them as auxiliaries foreign to his art;"* straps, however, may be made extremely useful in the practice of carpentry, particularly in such cases as the suspension of the tie-beam to the king post, and to secure the feet of the principal rafters to the tie-beam of a roof.

Strap for King or Queen Post.—In Fig. 81, Art. 250, *s* shows a strap or stirrup for suspending the tie-beam to a

* 'Encyclopædia Britannica,' art. Carpentry.

king or queen post; its hold of the post may be improved by turning the ends, as at *d d*, in the section E; these, when well fitted, will, with the addition of bolts, give the strap a firm hold; or staples, as in Fig. 149, may be used for a slight roof. The strengths of straps for different bearings are stated below. When the longest unsupported part of the tie-beam is

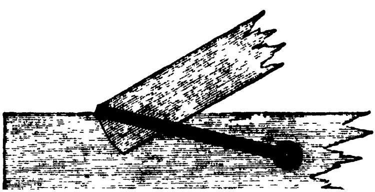
10 feet,	the strap may be	1 inch	wide by	$\frac{3}{16}$	inch thick.
15	,, ,,	$1\frac{1}{2}$	,,	$\frac{1}{4}$	,,
20	,,	2	,,	$\frac{1}{4}$	,,

These dimensions are quite sufficient for common purposes, but where the machinery of a theatre, or other heavy loads, are to be borne by the tie-beams, the straps must be made stronger in proportion to the load.

Where suspending pieces are used instead of queen posts, the same kind of strap will apply, as shown in Fig. 151.

431. *Strap at the Foot of a principal Rafter.*—A strap at the foot of a principal rafter is intended to form an abutment for it, in case the end of the tie-beam should fail. If the strap be put too upright it will become quite loose when the roof settles, instead of forming an abutment; and as it is in-

FIG. 155.



tended to prevent the foot of the rafter sliding along the tie-beam, an oblique position, as shown by Figs. 144 and 155, will be the most effectual. Straps of the same size as are

used for the king post will be sufficient. In bolting on straps they ought to be drawn tight. Price recommends square bolts for this purpose. He says, "If you use a round bolt, it must follow the auger, and cannot be helped; but by helping the auger-hole, that is, by taking off the corners of the wood, you may draw a strap exceedingly close, and at the same time cause it to embrace the grain of the wood in a much firmer manner than a round pin." *

Sometimes a bolt put through square from the back of the rafter is used with cross plates at the head and nut. Fig. 144 shows this method, the dotted lines representing the bolt.

432. *Bolts, Nuts, and Washers.*—The following proportions will be found suitable for the bolts, nuts, and washers used in carpentry:—

Diameter of Bolt	= 1	
Diameter of Head and Nut Rose square or hexagon from side to side	= $1\frac{3}{4}$	
Thickness of Head	= $\frac{3}{4}$	of diameter of bolt.
Depth of Nut	= 1	"

Washers should equal half the thickness of the head, and have twice the diameter, otherwise they will indent the timber on the nut being screwed up tight.

433. *Screws.*—The following experiments were made by Mr. Bevan on the force necessary to draw screws of iron, commonly called wood screws, out of given depths of wood.

The screws he used were about 2 inches in length, $\frac{22}{100}$ of an inch in diameter at the exterior of the threads, $\frac{15}{100}$ of an inch diameter at the bottom, the depth of the worm or thread being $\frac{35}{1000}$ of an inch, and the number of threads in one inch = 12. The screws were passed through pieces of wood

* 'British Carpenter,' p. 18.

exactly half an inch in thickness, and were drawn out by the weights specified in the following Table:—

	lbs.		lbs.
Dry Beech	460	Dry Mahogany	770
,, ,, ...	790	Dry Elm	655
Dry Sound Ash	790	Dry Sycamore	830
Dry Oak	760		

The weights were supported about two minutes before the screws were extracted.

Mr. Bevan also found that the force required to draw similar screws out of deal and the softer woods was about half the above.

From these experiments we may infer as a rule that the full force of adhesion of screws in Hard Wood is

$$200{,}000\, d\, \delta\, t = f,$$

and in Soft Wood is

$$100{,}000\, d\, \delta\, t = f,$$

d being the diameter of the screw, δ the depth of the worm or thread, and t the thickness of the wood into which it is forced—all in inches; f being the force in pounds required to extract the screw.*

434. *Nails.*—Theoretical investigation points out an equality of resistance to the force of entrance and extraction of a nail, supposing the thickness to be invariable; but as the usual shape of nails is tapering towards the points, the resistance to entrance becomes of necessity greater than that of extraction; in some of Mr. Bevan's experiments the ratio was found to be about 6 to 5.

The following Table will show the relative adhesion of nails of various kinds when forced into dry Christiana deal, at right angles to the grain of the wood.

* 'Phil. Mag.,' 1827.

A sixpenny nail, driven into Dry Elm to the depth of 1 inch across the grain, required a pressure of 327 lbs. to extract it. And the same nail, driven endways, or longitudinally into the same wood, required a force of 257 lbs. to extract it.

The same nail driven 2 inches endways into dry Christiana deal, was drawn out by a force of 257 lbs.; to draw it when driven only 1 inch, under like circumstances required 87 lbs.

The relative adhesion, therefore, in the same wood, when driven transversely and longitudinally, is 100 to 78, or about 4 to 3 in dry elm, and 100 to 46, or about 2 to 1 in deal.

The relative adhesion, under like circumstances, to elm and deal, was found to be about 2 or 3 to 1.

The progressive depths of a sixpenny nail into dry Christiana deal by simple pressure were as follows :—

¼	inch, a pressure of	.. .. ..	24 lbs.
½	,, ,,	.. .. ..	76 ,,
1	,, ,,	.. .. ..	235 ,,
1½	,, ,,	.. .. ..	400 ,,
2	,, ,,	.. .. ..	610 ,,

In performing the above experiments great care was taken to apply the weights steadily, and that towards the conclusion of each experiment the addition did not exceed 10 lbs. at a time, with a moderate interval between, generally about a minute, sometimes ten or twenty minutes.

In other pieces of wood the requisite force to extract the nail was different. Thus, to extract a common sixpenny nail from a depth of 1 inch

Out of	Dry Oak required	507 lbs.
„	Dry Beech	667 „
„	Green Sycamore	312 „

A common screw of $\frac{1}{5}$th of an inch diameter was found to have an adhesion of about three times that of a sixpenny nail.*

It was found by Mr. Bevan that the force required to cause sliding or separation in the plane of the joint of two pieces of Christiana deal, each $\frac{7}{8}$ths of an inch thick, when nailed together with two sixpenny nails, was 712 lbs. The time was fifteen minutes; the nails curved a little and were then drawn.

When the wood was dried Oak 1 inch thick, the force required to cause complete separation was 1009 lbs.

Dry sound Ash 1 inch thick yielded with 1420 lbs.

435. *Iron Shoes and Sockets.*—In the practice of modern carpentry, iron is extensively employed for securing the ends of pieces of timber, and in various ways to strengthen the joints.

When placed at the lower end of a post or strut, subject to compression only, it is called a "shoe," and for this purpose cast iron, from the ease with which it can be moulded to shape, and its capability of resistance to crushing, is most commonly used. Iron shaped to receive the end of a piece

* 'Phil. Mag.,' vol. lxiii., 1824.

of timber liable to extensile or transverse strain, is called a "socket," and is most frequently made of wrought iron. The drawings at the end of this work show a variety of modes of applying shoes and sockets in the carpentry of roofs, centres, coffer-dams, &c.

436. *Preservation of Iron.*—It must be remembered that thin plates and small pieces of iron decay very rapidly, particularly in damp situations; therefore they should be well secured against rust by being painted as soon as they are made. Smeaton, writing on this subject, says, "I had observed that when iron once gets rust, so far as to form a scale, whatever coat of paint or varnish is put over this, the rust will go on progressively under the paint." The method he used to prevent iron from rusting was to heat it to about a blue heat, and immediately strike it over the surface with raw linseed oil: the next day, if properly done, it appears as if a coat of varnish had been laid on.* By this method the pores of the iron become filled, and effectually protected from corrosion.

Coating the iron while hot with a mixture of tar and asphalte is a good preservative.

Another method, that is easily applied to small articles, consists in heating the metal, and rubbing it over, while hot, with wax. By this process the iron acquires an extremely uniform coating.

Nails and other small fastenings might be rendered much more lasting by boiling them in linseed oil. This is often practised by slaters to protect their nails from rust.

As it is difficult to heat large articles, a coating that can be applied in a cold state is much better. One that dries quickly, and, it is said, perfectly preserves from rust the metals upon which it is laid, is described in the 'Repertory of

* 'Historical Account of the Construction of Eddystone Lighthouse,' p. 182.

Arts.'* It is prepared as follows: Grind to an impalpable powder 1 part (by weight) of black-lead (plumbago), with which mix 4 parts of sulphate of lead, and 1 part of sulphate of zinc: to this mixture add, by degrees, 16 parts of boiled linseed oil.

Coating with zinc, called galvanizing, is now commonly used, but it is destroyed by the fumes of sulphuric and muriatic acid, consequently it is more liable to decay where much coal is burned, or near the sea, than elsewhere.

437. *Adhesion of Glue.*—Although glue is much used by the joiner it is seldom so by the carpenter, but as some knowledge of its strength and mode of application may be useful, the following information is given.

To ascertain the strength of common glue Mr. Bevan obtained two cylinders of dry ash, each 1½ inch in diameter and about 8 inches long, which he glued together end to end. After being allowed to rest for twenty-four hours, he found that they required a force of 1260 lbs. to separate them; and as the area of the surface in contact was 1·76 square inch, it follows that a force of 715 lbs. would be required to separate *one square inch.* The glue used in this experiment was fresh made, and the season very dry.

In some former experiments made by Mr. Bevan during the winter season, and with glue which had been frequently melted with occasional additions of fresh glue and water, he found a result of 350 lbs. to 560 lbs. to the square inch. The present experiment was made with great care, and every precaution taken to ensure that the direction of the force passed the centre of the surfaces in contact.

The pressure was applied gradually, and was sustained for two or three minutes before separation took place. Upon examining the separated surfaces, the glue appeared to be very thin, and did not entirely cover the wood, so that the

* 'Repertory of Arts, &c.,' second series, vol. xxvii., p. 314.

actual cohesion of glue must be something greater than 715 lbs. to the square inch.

The lateral cohesion of a piece of board cut out of Scotch fir, which had been quite dry and seasoned, was 562 lbs. to the square inch. Therefore if two pieces of this board had been well glued together, the wood would have yielded in its substance before the glue.

The cohesion of a piece of solid glue, or the force required to separate one square inch, Mr. Bevan found to be 4000 lbs.*

Good glue in the cake is very hard, and appears clear and partly transparent when held before the light. It swells in water on being steeped, but does not readily dissolve.

To prepare glue it should be broken into small pieces and steeped in the water for about twelve hours; it should then be submitted to a gentle heat until it becomes sufficiently dissolved for use.

When it is required to glue up work, the parts which are to receive the glue should be made perfectly clean and smooth, and the wood should be thoroughly dry, the glue should also be applied as hot as possible.

The strength of common glue for coarse work is increased by the addition of a little powdered chalk. Skimmed milk in the proportion of 1 lb. of glue to 2 quarts of milk is sometimes used to dissolve glue with the view of increasing its capability of resisting moisture.

Marine Glue is made of 1 part of india-rubber, 12 parts of mineral naphtha or coal-tar, gently heated and mixed, to which is afterwards added 20 parts of powdered shellac. It is then poured out on a slab to cool. In using, it must be heated to about 250°. A good glue for outside work is sometimes made by grinding as much white-lead with linseed oil as will just make the liquid of a whitish colour and strong but not too thick.

* 'Phil. Mag.,' 1826.

SECTION XII

TIMBER.

438. Wood is that substance which forms the principal part of the roots, trunks, and branches of trees and shrubs; and its usefulness in the art of construction is well known.

The *woods* of different trees differ much in strength, hardness, durability, and beauty; and, consequently, in their fitness for the various purposes to which they are applied. The wood which is felled and seasoned for the purpose of building is called *timber;* and in stating the properties of woods, those only shall be considered which are fit for timber.*

439. If the stem or trunk of a tree be cut across, the wood is found to be made up of numerous concentric layers or rings; very distinct in some trees, but less so in others. One of these layers is usually formed every year; consequently their number corresponds nearly with the age of the tree. Each layer consists, in general, of two parts; the one solid, hard, heavy, and dark coloured; the other of a lighter colour, porous, and soft; which renders the lines of separation between the annual layers distinct. Scarcely any two layers of the same tree are precisely alike, either in the proportion of the hard part, or in the thickness of the layers;

* *Timber* is derived by Dr. Johnson from the Saxon *timbrian*, to build; hence the above definition: but it is more probable that the term is derived from the French *timbrien*, to mark or stamp—denoting trees marked for being cut. The legal definition of timber is restricted to particular species of wood, and custom varies in different counties as to the species ranked among the timber trees.

as the layers vary in thickness according to the degree of vegetation which took place in the years of their formation: and also in the same tree they vary in thickness, either according to the situation of the principal roots, or the aspect; the annual layers being always thicker on that side of the tree which has been most favourable to the growth of the roots, or that which has had the advantage of a good aspect.

Wood appears to be composed of various vessels, which, in the living tree, convey the fluids necessary to its growth; between those vessels there are cells interposed. There is nothing of the character of solid fibres in wood, except the thin membraneous coats of the cells and vessels, which adhere so slightly together in recently formed wood, that it is easy to separate them. The vessels in the growing tree are intended to convey a watery fluid, called the sap, from the roots to the leaves; when it arrives at the leaves it undergoes some changes and returns through the bark;* and the bark being expanded by this accession of moisture, rises from the wood, and leaves a cavity that becomes filled with the proper sap, which gradually hardens and forms a new layer of wood. The rising sap flows chiefly through the annual rings next the bark; and from the experiments of Mr. Knight,† it appears that the sap during its ascent dissolves some portion of a substance that had been deposited in the vessels of the wood during the preceding winter, for the nourishment of the buds, leaves, and young wood; hence the flowing sap is more dense in the upper than in the lower part of a tree. Dr. Darwin draws a like conclusion from the debarked oaks producing leaves.‡

* Art. Anatomy, Vegetable, 'Encyclopædia Britannica.'

† 'Philosophical Transactions,' 1805.

‡ 'Phytologia,' p. 159. The fact may be owing entirely to the fluid being reduced by evaporation.

In trees, as the leaves expand the sap ceases to flow, and the bark again adheres to the wood; and from the middle of June to the middle of August there appears to be a pause in vegetation; but after this period the sap again begins to flow, and the bark which adhered so closely in the preceding months may be separated almost as easily as in the spring.

440. The sap which rises through the wood from the roots is very different in its nature from that which descends through the bark to form the new layer of wood. That which ascends is nearly as liquid as water, and is called the *common sap.* It has in general a sweetish taste, and contains sugar and mucilage. It always contains an acid, sometimes in a free state, sometimes combined with lime or potash. When this sap is left to itself, it soon ferments and becomes sour; and when the proportion of sugar is considerable, it will undergo the vinous fermentation.*

The descending sap, called the *proper sap*, differs so considerably in different trees, and is so difficult to procure in a separate state, that its properties have not been closely examined. It is always less liquid, and contains a much greater proportion of vegetable matter than the common sap. It is also very probable that trees of the same kind produce proper sap of different qualities in different climates, as we find that the facts established respecting timber grown in one climate are not applicable to the same species of timber grown in another.

441. That part of the wood next the bark is called *sap-wood*, because it is through it chiefly that the sap ascends; and as it is shown by Mr. Knight to contain some vegetable matter to be expended in forming leaves and buds, it is reasonable to suppose from analogy that the sap-wood must

* The properties of the different kinds of sap that have been examined are given in Dr. Thomson's 'System of Chemistry,' iv., 209–213.

be more prone to decay than the internal part of the tree, called the heart-wood.

As trees increase in size the oldest part of the sap-wood gradually loses all vegetable life, and the more fluid parts of it are either absorbed by the new forming sap-wood or evaporated; its vessels and cells become closed by the pressure of the new-forming wood, and it ceases to perform any other part in the growth of a tree than to support it. When these changes have taken place it is found to be more compact, and generally of a darker colour; and also contains only a small proportion of vegetable matter besides that kind which is called the *woody fibre* by chemists. It is then heart-wood, or wood in its most perfect state.

The sap-wood is softer and generally lighter coloured than the heart-wood, and contains a considerable portion of vegetable matter, which partakes of the nature of the sap which ascends through it. It is found to decay rapidly, and is also very subject to the attack of worms. The reason is obvious, for it contains the food upon which they live, the most of which is absorbed or evaporated from the heart-wood.*

The proportion of sap-wood in different trees varies considerably; Spanish chestnut has a very small proportion of sap-wood, oak has more, and fir a still larger proportion than oak; but the proportions vary according to the situation and soil. Three specimens of a medium quality gave the following:—

Chestnut,	whole age	58 years,	15½ in. diam.,	7 years sap-wood,	⅜ in. thick.	
Oak	„	65 „	17 „	17 „	1¼ „	
Scotch fir			24 „		2½ „	

* In many woods the line of demarkation between the heart and sap-wood is so strongly defined, that, as a friend well remarks, "the change seems to take place, as it were, per saltum:" it certainly is a singular phenomenon, and merits more of the attention of physiologists than it has received.

Therefore, if the diameter be unity, or 1, that part of it which is sap-wood will be, in the chestnut, 0·1; in the oak, 0·294; and in the Scotch fir, 0·416. The Scotch fir was the produce of the Mar Forest.*

442. The life of trees, like that of men, has been commonly divided into three stages, infancy, maturity, and old age. In the first, the tree increases from day to day; in the second, it maintains itself without sensible gain or loss; but in the third, it declines. These stages vary in every species according to the soil, the aspect, the climate, or the nature of the individual plant.

Sir H. Davy states† that oak and chestnut trees decay sooner in a moist soil than in a dry and sandy one, and their timber is less firm. The sap vessels being expanded with moisture wanting a sufficient quantity of nourishing matter, the general texture necessarily becomes less firm. Such wood splits easily, and is very liable to shrink and swell with the changes of the weather.

Trees of the same kind arrive at the greatest age in that climate which is best adapted to their nature. The common oak, fir, and birch thrive best towards the northern; the ash and the olive tree thrive best towards the southern parts of Europe.

We find, says Mirbel, the ash-trees of Calabria and Sicily to be longer lived than those of Prussia or Great Britain.‡ Oak and chestnut trees, under favourable circumstances, sometimes attain an age of about 1000 years; beech, ash, and sycamore, seldom arrive at half that age.

The decline of trees appears to be caused by the decay of the heart-wood; it is this, as Sir H. Davy remarks,§ which

* These measures were taken from specimens in the collection of William Atkinson, Esq., Surveyor to the Board of Ordnance.

† 'Agricultural Chemistry,' p. 255, 8vo edit.

‡ 'Journal of Science, &c.,' vol. iv., p. 11.

§ 'Agricultural Chemistry,' p. 220, 4to edit.

seems to constitute the great limit to the age and size of trees; and the long period the central parts are preserved by the cooling influence of the living trees is truly wonderful.

In trees that have not arrived at maturity, the hardness and solidity of the wood are greatest at the heart, and decrease towards the sap-wood; but in the mature or perfect tree the heart-wood is nearly uniform; while that of a tree on the decline is softer at the centre than it is next the sap-wood. These observations were made by Buffon in the course of his numerous experiments, and also by Duhamel.

Felling Timber

443. "It should be," says the venerable Evelyn, "in the vigour and perfection of trees that a felling should be celebrated."* When a tree is felled too soon, the greater part of it is sap-wood, and in a young tree even the heart-wood has not acquired its proper degree of hardness; indeed the whole tree must partake so much of the nature of sap-wood, that it cannot be expected to be durable. And when a tree is not felled till it be on the decline, the wood is brittle and devoid of elasticity, tainted, discoloured, and soon decays. But in trees that have arrived at a mature age, the proportion of sap-wood is small, and the heart-wood is nearly uniform, and is hard, compact, and durable. Hence it is important that Evelyn's precept should be carefully attended to. It is true that the proper age for felling each species has not been satisfactorily determined, but it is a point where great accuracy is not necessary; for half-a-dozen years in the age of a tree will not make much difference, provided it be not cut too soon. Trees increase slowly in size after they arrive at a certain age, therefore it becomes the interest of the timber grower to fell them before they arrive at maturity; because

* 'Silva, or a Discourse on Forest Trees,' vol. ii., p. 205.

it is his object to obtain the greatest possible quantity of timber, without regard to the quality. But the carpenter who is aware of the inferior quality of young timber in respect to duration, should endeavour to check this growing evil, by giving a better price for timber that has acquired its proper degree of density and hardness.

The period generally allowed for an oak-tree to arrive at maturity is 100 years, and the average quantity of timber produced by a tree of that age is about 1½ load, or 75 cubic feet. In some instances oak-trees arrive at maturity in less time than 100 years, and in others not until after that period.*

The age of an oak-tree, according to Daviller, should never exceed 200 years, nor should it be felled at a less age than 60.† Belidor states about 100 to be the best age for the oak.‡ It is much to be regretted that in districts where the oak flourishes it is seldom suffered to attain a mature age; being often cut before the trees will produce 50 feet of timber each.§

The ash, larch, and elm should be cut when the trees are between 50 and 100 years old; and between 30 and 50 is a proper age for poplars.

The Norway spruce and Scotch pine are generally cut when between 70 and 100 years old in Norway.

444. In order that timber may be durable it is also necessary to attend to the proper season of the year for felling. But on this point there is much difference in opinion, and the question is only to be decided by attending to the state of trees at different seasons of the year. The best period for felling timber is undoubtedly that in which it is most free

* 'First Report of the Commissioners of Woods and Forests,' pp. 24 and 25, 1812.

† 'Cours d'Architecture.'

‡ 'Science des Ingénieurs,' liv. iv., chap. i.

§ See Marshall's 'Southern Counties,' vol. ii., p. 127.

On the other hand, the best time for felling timber is in mid-winter or mid-summer, as at these times the vegetative powers are at rest, or have expended all the most changeable parts in producing leaves, &c. In some kinds of trees, a little after mid-summer appears to be decidedly the best time for felling. Alder felled at that time is found to be much more durable; and Ellis says that beech, when cut in the middle of summer, is better and less liable to worm-eat; particularly if a gash be cut to let out the sap some time before felling.† Mr. Knowles states that "about Naples, and in other parts of Italy, oaks have been felled in summer, and are said to have been very durable." ‡ And as summer felling is an advantage in some species, it seems reasonable to conclude that it will be so in all.

* 'Philosophical Transactions,' 1805.

† Ellis's 'Timber Tree Improved,' p. 35.

‡ 'Inquiry into the Means which have been taken to Preserve the British Navy," p. 20, 4to, 1821.

445. But in oak-trees the bark is too valuable to be lost; and as the best period for the timber is the worst for the bark, an ingenious method has been long partially practised, which not only secures the bark at the best season, but also materially improves the timber. This method consists in taking the bark off the standing tree early in the spring, and not felling it until after the new foliage has put forth and died. For by the production of new buds the fermentable matter is expended, and the sap-wood becomes nearly as hard and durable as the heart-wood, being both less liable to decay and to be destroyed by worms.

Buffon has ascertained by experiment that the wood is materially improved by this method of barking the trees standing in the spring, and felling them about the end of October.* Duhamel, whose extensive knowledge of the nature and qualities of woods is well known, recommends the same method; and Evelyn states that "to make excellent boards and planks, it is the advice of some that you should bark your trees in a fit season, and so let them stand naked a full year before felling." † But a tree will not be benefited by standing so long; and the best time for felling appears to be when the new foliage has put forth and died, as Mr. S. Pepys observes in his paper on the subject: ‡ and Mr. T. A. Knight, to whom we are indebted for many interesting as well as important facts respecting timber, has made some experiments and observations, from whence he concludes that in all cases where it is essential to give durability to the sap-wood of oak, the trees should be barked in the spring, and felled in the ensuing winter; § also that winter-felled heart-wood is less

* "Moyen facile d'augmenter la Solidité, la Force, et la Durée du Bois;" 'Mémoires de l'Académie des Sciences,' Paris, 1738, pp. 169–184.

† 'Silva,' Dr. Hunter's edition, vol. ii., p. 214.

‡ 'Philosophical Transactions,' vol. xvii., p. 455.

§ 'Annals of Philosophy,' vol. xiv., p. 52, or 'Phil. Trans.,' 1826.

A similar effect might be produced by placing the timber on its end as soon as it is felled, and it would no doubt compensate for the extra expense by its increased durability.

In France, so long ago as 1669, a royal ordinance limited the felling of naval timber from the 1st of October to the 15th of April. Buonaparte directed that the time for felling naval timber should be from the 1st of November to the 15th of March, in order to render it more durable.†

SEASONING TIMBER.

446. *Natural Seasoning.*—When timber is felled, the sooner it is removed from the forest the better; it should be removed to a dry situation, and placed so that the air may circulate freely around each piece, but it should not be exposed to the sun and wind. Squared timber does not rift or

* 'Vitruvius,' book ii., chap. ix.

† 'Encyclopædia Britannica,' art. Dry Rot.

split so much as that which is round. After the trees have been allowed to dry slowly, and where the size will allow of it, it is better to quarter them. When beams are to be used the full size of the tree, it would be a good preservative against splitting to bore them through from end to end, as is done in a water-pipe. It is irregular drying which causes timber to split, and this method would assist in drying the internal part of the beam, without causing much loss of strength, at the same time it would lighten the beam considerably. "Ancient architects," says Alberti, "not only prevented the access of the scorching rays of the sun and the rude blasts of wind, but also covered the surface with cow-dung to prevent the too sudden evaporation from the surface." *

Duhamel has shown that it is a great advantage to set the timber upright, with the lower end raised a little from the ground;† but as this cannot always be done, the timber-yards should be well drained, and kept as dry as possible. Paved yards are to be preferred, and the paving should have a considerable fall, to prevent water standing. If the paving were laid with ashes it would be better; those from a forge or foundry would be excellent: even an unpaved yard would be improved by a coat of ashes, to prevent anything growing among the timber.

If timber can be kept some time in a dry situation before it is cut into scantlings, it will be less subject to warp and twist in drying; but during the time it is kept in the tree or log it should be carefully piled, so as to leave space for a free circulation of air between each piece, and also between the timbers and paving or ground. Lately, in some of the Government yards, the timber has been laid upon cast-iron bearers, instead of being laid upon refuse pieces of wood; as the refuse wood is often half rotten, and must in some degree

* Book ii., chap. v

† 'Transport des Bois,' p. 238.

contribute to infect the sound timber. Timber is too often suffered to lie half buried in the ground, or grown over with weeds, until it is covered with fungus, and impregnated with the seeds of decay before it is brought into use.

When it is necessary to convert the timber into smaller scantlings, it still requires attention; as the better it is seasoned, when brought into work, the better the work will stand; it will also be more durable. The experiments of Duhamel show that such scantlings will dry soonest in an upright position, and that the upper end dries more rapidly than the lower one.* But whether the pieces of timber be piled on the end, or laid horizontally, a free space should be left round each, and the situation should be dry and airy; they should not be exposed to the direct rays of the sun, nor to a strong current of air. If the pieces be laid horizontally, short blocks should be put between them, which will preserve them from becoming mouldy, and will contribute much towards rendering the sappy parts more durable.

Gradual drying, where the time can be allowed for it in the natural process, is the most certain means of giving durability to timber, by fixing those parts of it which are most liable to be acted upon by heat and moisture.

It is well known to chemists that slow drying will render many bodies less easy to dissolve, while rapid drying, on the contrary, renders the same bodies more soluble; besides, all wood in drying loses a portion of its carbon, and the more in proportion as the temperature is higher. There is, in wood that has been properly seasoned, a toughness and elasticity which is not to be found in rapidly-dried wood. This is an evident proof that firm cohesion does not take place when the moisture is dissipated in a high heat. Also, that seasoning by heat alone, produces a hard crust on the surface,

* 'Transport des Bois,' p. 83.

which will scarcely permit the moisture to evaporate from the internal part, and is very injurious to the wood.

For the general purposes of carpentry, timber should not be used in less than two years after it is felled; and this is the least time that ought to be allowed for seasoning. For joiners' work it requires four years, unless other methods be used; but for carpentry natural seasoning should have the preference, unless the pressure of the air be removed.

Duhamel says that the quantity of matter which ought to be evaporated from green oak is about one-third or two-fifths of its weight; the proportion, however, will vary according to the age and quality of the timber, and the nature of the soil that produced it.* The time required to dry a piece of timber will depend on the scantling and on the surface exposed to the action of the air.

Equal drying should be promoted by frequently turning the pieces, and by keeping them free from the ground or other damp situations.

The evaporation is greater from the ends of a piece of timber than from the sides, and greater from the upper than from the lower side.

There are two states in which timber is used in building, *viz.* when it is *dry*, and when it is only *seasoned*. The latter term has not been very accurately defined. Rondelet considers timber to be sufficiently seasoned for carpenters' work when it has lost about *one-sixth* of its weight. According to the author's own observations, timber has undergone what is termed a proper seasoning for common uses when it has lost about one-fifth of its weight; therefore we shall call that timber *seasoned* which has lost *one-fifth* of the weight it had at the time of felling.

It also appears from the experiments of Duhamel † and

* 'Transport des Bois,' p. 72.

† 'Transport des Bois.'

Couch,* that timber loses about one-third of its weight in becoming dry; and such a degree of dryness being sufficient for the joiner's purpose, we shall consider timber *dry* when it has lost *one-third* of its weight.

Thus the terms *dry* and *seasoned* will have a more certain meaning; and when drying is carried to its greatest extent, the timber may be called *perfectly dry*, to distinguish it from that degree of dryness which renders it fit for framing and joiners' work.

447. In order to compare the times required to season and to dry timber when the sizes of the pieces remain the same, it will be necessary to consider the progress of evaporation from the same quantity of surface.

Let the whole time be conceived to be divided into equal parts, then if the quantity evaporated during any one of these parts of the time be n W, the whole quantity of sap being W; then as the time increases, the quantity of moisture decreases; and the force of evaporation being proportional to the excess of moisture, the quantity evaporated must decrease as the time increases, and the time is expressed by the equation $W\left(1 - \frac{1}{n}\right)^t = w$, when w is the quantity of moisture the wood retains.†

But for calculation we must employ logarithms, and then if $\frac{W}{w} = m$, the equation becomes $\frac{\log. m}{\log. n - \log. (n - 1)} = t$ the time.

When timber is dry $m = 12$; and in seasoning in the open air $n = 20$ nearly; the timber losing one-third of its weight; but in seasoned timber $m = 2 \cdot 5$, and $n = 15$; the time being expressed in months.

* Barlow's 'Essay on Timber.'

† The investigation is given in the author's 'Treatise on Warming and Ventilating Buildings, &c.'

Hence it appears how slowly the process of drying goes on; and the preceding equations showing that it proceeds most rapidly in small pieces, the importance of reducing timber to its proper scantlings for use is obvious. For however dry a piece of timber may be, when it is cut to a smaller scantling it will still shrink and lose weight, being always less dry in the centre than at the surface; and the more rapidly the drying has been carried on, the greater will be the difference. Nevertheless, in the first stages of seasoning it is best that it should proceed slowly; otherwise the external pores would shrink so close as not to permit the free evaporation of the internal moisture, and the piece would split from unequal shrinking; and, lastly, it should be reduced nearly to the proper scantling some time before it be framed.

448. The following Table gives the relative time of seasoning pieces of timber in the open air calculated according to the foregoing Rule.

Length in feet.	Breadth in inches.	Thickness in inches	Time of Seasoning in months.	Time of Drying in months.
10	6	6	6½	29
10	8	8	8½	39
12	10	10	10	48
12	12	12	12	57
12	14	14	14	66
12	16	16	17	76
18	18	18	19	86
20	20	20	21	96

The time required to season timber under cover is reduced in the proportion of 5 to 7.

449. The following Table shows the Shrinkage and Loss of Weight in Seasoning of the principal Timbers used in Ship-building. The period of seasoning was ten years.*

* Fincham's 'Outlines of Ship-building,' 3rd edition.

Species of Timber		Green. Size.	Green. Weight.	Seasoned. Size.	Seasoned. Weight.	Weight of a cubic foot. Green.	Weight of a cubic foot. Seasoned.
		in. in.	lbs. ozs.	in. in.	lbs. ozs.	lbs.	lbs.
English Oak	butt	6 by 6	7 8	6 by $5\frac{14}{16}$	6 7	60	51½
	top	,,	7 10	$5\frac{14}{16}$,, $5\frac{15}{16}$	6 6	61	51
	butt	,,	8 0	$5\frac{15}{16}$,, $5\frac{14}{16}$	6 5	64	50½
	top	,,	7 4	$5\frac{15}{16}$,, $5\frac{15}{16}$	6 0	58	48
Dantzic Oak	butt	,,	7 2	$5\frac{14}{16}$,, $5\frac{15}{16}$	5 12	57	46
	top	,,	7 0	$5\frac{14}{16}$,, 6	5 15	56	47½
	butt	,,	6 7½	$5\frac{13}{16}$,, $5\frac{14}{16}$	5 4	51¾	42
	top	,,	6 9	$5\frac{14}{16}$,, $5\frac{14}{16}$	5 2½	52½	41¼
African Oak	butt	,,	9 2	$5\frac{12}{16}$,, $5\frac{12}{16}$	8 0	73	64
	top	,,	8 6	$5\frac{13}{16}$,, $5\frac{13}{16}$	7 2	67	57
	butt	,,	7 12	$5\frac{13}{16}$,, $5\frac{14}{16}$	7 2	62	57
	top	,,	7 4	$5\frac{14}{16}$,, $5\frac{15}{16}$	6 10	58	53
Cowrie ..	butt	,,	4 14½	$5\frac{14}{16}$,, 6	4 6½	38½	35¼
	top	,,	4 9	$5\frac{14}{16}$,, $5\frac{14}{16}$	4 0	36½	32
	butt	,,	4 10	$5\frac{14}{16}$,, $5\frac{14}{16}$	4 2½	35	33¼
	top	,,	4 7½	$5\frac{14}{16}$,, $5\frac{14}{16}$	4 1¾	35¾	32¾
Italian Larch	butt	,,	4 15	$5\frac{15}{16}$,, $5\frac{14}{16}$	4 8	39½	36
	top	,,	4 15	$5\frac{14}{16}$,, $5\frac{14}{16}$	4 9	39½	36½
	butt	,,	5 0	$5\frac{14}{16}$,, $5\frac{14}{16}$	4 9½	40	36¾
	top	,,	5 1	$5\frac{15}{16}$,, $5\frac{14}{16}$	4 11	40½	37½
Scotch Larch	butt	,,	4 8	$5\frac{14}{16}$,, $5\frac{14}{16}$	4 2½	36	33¼
	top	,,	4 10	$5\frac{15}{16}$,, $5\frac{15}{16}$	4 1	37	32½
	butt	,,	4 5	$5\frac{15}{16}$,, $5\frac{14}{16}$	4 0	34½	32
	top	,,	3 12	$5\frac{14}{16}$,, $5\frac{14}{16}$	3 7	30	27½
Hackmetack Larch ..	butt	,,	5 14	$5\frac{12}{16}$,, $5\frac{12}{16}$	4 13	47	38½
	top	,,	5 6	$5\frac{13}{16}$,, $5\frac{12}{16}$	4 3	43	33½
	butt	,,	5 7	$5\frac{14}{16}$,, $5\frac{12}{16}$	4 8	43½	36
	top	,,	4 15	$5\frac{13}{16}$,, $5\frac{14}{16}$	4 6	39½	35
English Elm	butt	,,	5 9½	$5\frac{13}{16}$,, $5\frac{12}{16}$	4 10½	64¾	37¼
	top	,,	5 11¼	$5\frac{14}{16}$,, $5\frac{13}{16}$	4 9	59¾	36½
	butt	,,	6 4	$5\frac{14}{16}$,, $5\frac{13}{16}$	4 11¾	60	39¾
	top	,,	5 7	$5\frac{12}{16}$,, $5\frac{12}{16}$	4 3½	53¼	33¾
Canada Elm	butt	,,	7 10	$5\frac{12}{16}$,, $5\frac{12}{16}$	7 2	61	57
	top	,,	6 9	$5\frac{11}{16}$,, $5\frac{12}{16}$	5 5	52½	42½
	butt	,,	7 1	$5\frac{11}{16}$,, $5\frac{12}{16}$	6 8	56½	52
	top	,,	6 2	$5\frac{12}{16}$,, $5\frac{14}{16}$	4 13	49	38½

TABLE—*continued.*

Species of Timber.		Green.		Seasoned.		Weight of a cubic foot.	
		Size.	Weight.	Size.	Weight.	Green.	Seasoned.
		in. in	lbs. ozs.	in. in.	lbs. ozs.	lbs.	lbs.
Cuba Cedar	butt	6 by 6	4 0	$5\frac{15}{16}$ by $5\frac{15}{16}$	3 12	32	30
	top	”	4 3	$5\frac{15}{16}$ ” $5\frac{14}{16}$	3 $12\frac{1}{2}$	$33\frac{1}{2}$	$30\frac{1}{4}$
	butt	”	3 14	6 ” 6	3 0	31	24
	top	”	3 10	$5\frac{15}{16}$ ” 6	3 5	29	$26\frac{1}{2}$
N. S. Wales Cedar ..	butt	”	4 $0\frac{1}{2}$	$5\frac{15}{16}$ ” $5\frac{14}{16}$	3 10	$32\frac{1}{4}$	29
	top	”	3 12	$5\frac{15}{16}$ ” $5\frac{15}{16}$	3 $6\frac{1}{2}$	30	$27\frac{1}{4}$
	butt	”	4 6	$5\frac{15}{16}$ ” $5\frac{15}{16}$	3 8	35	28
	top	”	4 5	$5\frac{14}{16}$ ” $5\frac{14}{16}$	3 9	$34\frac{1}{2}$	$28\frac{1}{2}$
Pencil Cedar	butt	”	4 $5\frac{3}{4}$	6 ” 6	4 3	$34\frac{3}{4}$	$33\frac{1}{2}$
	top	”	4 5	6 ” 6	4 3	$34\frac{1}{2}$	$33\frac{1}{2}$
	butt	”	3 $10\frac{1}{2}$	6 ” $5\frac{14}{16}$	3 8	$29\frac{1}{4}$	28
	top	”	3 $12\frac{1}{2}$	6 ” 6	3 10	$30\frac{1}{4}$	29
Pitch Pine	butt	”	5 $11\frac{1}{4}$	$5\frac{15}{16}$ ” $5\frac{15}{16}$	5 $9\frac{1}{4}$	$45\frac{3}{4}$	$44\frac{1}{2}$
	top	”	4 $12\frac{1}{4}$	$5\frac{14}{16}$ ” $5\frac{15}{16}$	4 11	$38\frac{1}{4}$	$37\frac{1}{2}$
	butt	”	5 12	$5\frac{13}{16}$ ” $5\frac{15}{16}$	5 10	46	45
	top	”	4 14	6 ” $5\frac{15}{16}$	4 $12\frac{1}{4}$	39	38

450. A Table of the transverse Shrinkage in Seasoning of Boards 12 inches square and $\frac{1}{2}$ an inch thick. The period of seasoning was thirteen years.*

Species of Timber.		Shrunk in Seasoning	Species of Timber.		Shrunk in Seasoning.
English Oak..	butt	$\frac{1}{12}$ the breadth	Yellow Pine	butt	$\frac{1}{38}$ the breadth
	top	$\frac{1}{13}$ ” ”		top	$\frac{1}{48}$ ” ”
African Oak..	butt	$\frac{1}{27}$ ” ”	Larch..	butt	$\frac{1}{27}$ ” ”
	top	$\frac{1}{32}$ ” ”		top	$\frac{1}{48}$ ” ”
Riga Fir	butt	$\frac{1}{32}$ ” ”	English Elm	butt	$\frac{1}{24}$ ” ”
	top	$\frac{1}{32}$ ” ”		top	$\frac{1}{27}$ ” ”
Dantzic Fir ..	butt	$\frac{1}{38}$ ” ”	Canada Elm	butt	$\frac{1}{18}$ ” ”
	top	$\frac{1}{38}$ ” ”		top	$\frac{1}{21}$ ” ”
Virginia Pine	butt	$\frac{1}{27}$ ” ”	Cowrie	butt	$\frac{1}{64}$ ” ”
	top	$\frac{1}{38}$ ” ”		top	$\frac{1}{64}$ ” ”

* Fincham's 'Outlines of Ship-building,' 3rd edition.

451. *Water Seasoning.*—On account of the time required to season timber in the natural way, various methods have been tried to effect the same purpose in a shorter time. One of the best of these is to immerse the timber in water as soon as it is cut down, and after it has remained about a fortnight in water, but not more, to take it out, and dry it in an airy situation.

Evelyn directs, to "lay your boards a fortnight in water (if running the better, as at a mill-pond head) and then setting them upright in the sun and wind, so as it may pass freely through them, turning them daily; and, thus treated, even newly-sawn boards will floor far better than those of a many years dry seasoning, as they call it:"* and he adds, "I the oftener insist on this water seasoning, not only as a remedy against the worm, but for its efficacy against warping and distortions of timber, whether used within or exposed to the air."

Duhamel, who made many experiments on this important subject, states, that timber for the joiner's use is best put in water for some time, and afterwards dried; as it renders the timber less liable to warp and crack in drying; but, he adds, "where strength is required it ought not to be put in water."† And he found, from numerous experiments, that timber which had remained some time in fresh water lost more of its weight in drying than that which was dried under cover; and he observed that green timber that had been steeped in water for some time was always covered with a gelatinous substance.‡

Timber that has been cut when the tree was full of sap, and particularly when that sap is of a saccharine nature, must be materially benefited by steeping in water; because it will un-

* 'Silva,' vol. ii., p. 217. † 'Transport des Bois,' p. 247.
‡ Ibid., pp. 164, 168, 171.

doubtedly remove the greater part of the fermentable matter. Duhamel has ascertained that the sap-wood of oak is materially improved by it, being much less subject to be worm-eaten; and also that the tender woods, such as alder and the like, are less subject to the worm when water-seasoned.* Beech is said to be much benefited by immersion; and green elm, according to Evelyn, if plunged four or five days in water (especially salt water) obtains an admirable seasoning.†

When timber is put in water it must be sunk so as to be completely under water, as nothing is more destructive than partial immersion. Salt water is considered best for ship-timber, ‡ but for timber to be employed in the construction of dwelling-houses fresh water is better.

M. De Lapparent recommends the following periods for immersion in water:—In river water one year; in fresh water frequently changed two years; in brackish water, which should be always changing, three years.

At the close of these several periods the boards intended for planking should be taken out and placed in store, or they might be left to season themselves naturally for two years before being worked up. As to rough timber for ribs, it should always be submitted to artificial seasoning previous to being used.

452. *Steaming and Boiling Timber.*—Though steaming or boiling impairs the strength and elasticity of timber, it gives another property, which for some purposes is still more desirable than strength; for boiled or steamed timber shrinks less and stands better than that which is naturally

* 'Transport des Bois,' pp. 172 and 176.

† 'Silva,' vol. ii., p. 217.

‡ According to M. De Lapparent, Director of the French Dockyards, timber cannot be seasoned in salt water. 'Essay on the Prevention of Decay in Timber.'

seasoned. Therefore it may often be useful to season timber in this manner where joiners' work is to be executed in oak of British growth, as without this precaution it requires a long time to season it so as to be fit for such purposes.

The timber should not remain long in boiling water or steam; four hours will, in general, be quite sufficient: and after boiling or steaming, the drying goes on very rapidly, but it is well not to hasten the drying too much. Steamed wood dries sooner than that which is boiled, according to Mr. Hookey's experiments.*

How far steaming or boiling affects the durability of timber has not been satisfactorily ascertained; but it is said that the planks of a ship, near the bows, which are bent by steaming, have never been observed to be affected with the dry rot.† The changes produced by boiling, as observed by Duhamel, are not very favourable to the opinion that it adds to the durability of timber. For when a piece of dry wood was immersed in boiling water, and afterwards dried in a stove, it not only lost the water it had imbibed, but also a part of its substance; and when the experiment was repeated with the same piece of wood, it lost more of its substance the second time than it did the first. The same thing takes place in green wood; and tender woods, or those of a middling quality, are more altered by these operations than hard woods, or those of a good quality.‡ Dr. Watson found steeping long in cold water produced similar effects; and that box, oak, and ash lost more weight by this process than mahogany, walnut, or deal.§ Both cold and hot water has, therefore, to a certain extent, the power of dissolving the woody fibre.

* Barlow's 'Essay on the Strength of Timber.'

† 'Ency. Brit.,' art. Dry Rot.

‡ 'Transport des Bois,' pp. 138 and 144.

§ 'Chemical Essays,' vol. iii., p. 24.

453. *Smoke-drying, Scorching, and Charring Timber.*—It is an old and a well-founded observation, that smoke-drying contributes much to the hardness and durability of wood. Virgil seems to have been aware of its utility when he wrote the passage which is thus translated by Dryden:—

> "Of beech the plough-tail, and the bending yoke,
> Or softer linden *harden'd in the smoke.*" *
>
> *Georgics*, I., 225.

But this method can only be effectually applied on a very small scale; yet sometimes, for particular purposes, it may be useful to season in the smoke. As a substitute for the smoke of an open chimney, Ellis advises to burn fern, furze, straw, or shavings under the timber,† which would destroy any seeds of fungi or worms, and so embitter the external surface as to prevent any further ill-effect from either. It would be easy to contrive the means of smoke-drying for the use of a manufactory where much seasoned wood was used.

Scorching must do timber much harm when done hastily, as it causes rents and cracks, which become receptacles for moisture, and consequently cause rapid decay.

It must always be remembered that charring the surface is only useful in as far as it destroys and prevents infection; and that its application should be confined to timber already seasoned; for when applied to green timber, it closes up the

* Beckman (in his 'History of Inventions,' vol. ii., p. 77) quotes a passage from Hesiod to the same effect; and adds, "as the houses of the ancients were so smoky, it may be easily comprehended how, by means of smoke, they could dry and harden pieces of timber." In this manner were prepared the pieces of wood destined for ploughs, waggons, and the rudders of vessels:

> "These long suspend, where *smoke* their strength explores,
> And seasons into use, and binds their pores."
>
> SOTHEBY'S *Virgil.*

† 'Timber Tree Improved,' by Mr. Ellis.

pores at the surface, so that the internal sap and moisture cannot evaporate.

In that kind of decay which arises from the constant evaporation of moisture, charring the surface produces no effect. Duhamel made some experiments on this point, and found that there was very little difference between the posts he had charred, and those he had not charred, at the end of six years;* but as a preventive of infection by the dry rot, and of the worm in timber, charring appears to be very beneficial, and will no doubt be assisted by impregnating the timber with the bitter particles of smoke.

454. *Seasoning by the Extraction of Sap.*—In 1825 a method of separating the sap from the tree without injury to the woody fibre was patented by Mr. Langton. He placed the wood in vertical cylinders of iron, from which he exhausted the air by condensing steam within them; after they were closed heat was then applied by means of a water-bath surrounding the cylinders. The sap in the form of vapour was conveyed by pipes to vessels immersed in cold water, where it condensed and was collected in a liquid state for removal.

The wood seasoned in this manner rather exceeds the usual density of similar timber when dried to the same extent, and it loses about the same weight as in seasoning by the ordinary process, but shrinks somewhat more.

The process is said to be complete on the liquid ceasing to collect in the condensing part of the apparatus.

The time required to extract the whole of the sap is from eight to twelve weeks.†

455. *Seasoning by Hot Air.*—One of the best methods of artificial seasoning is that known as the Desiccating Process, introduced by Davison, which consists in exposing the timber

* 'Transport des Bois,' p. 225.

† 'Repertory of Patent Inventions,' vol. vi., p. 228.

to a current of air in a kind of oven. The air is impelled by a fan with a velocity of 100 feet per second; the fan, air-passages, and oven, or chamber, being so proportioned that a quantity of air equal to one-third of the volume of the space is blown through it per minute. An opening in the roof allows the moisture to pass away. Samples of the wood are weighed from time to time until it is found that the required proportion of weight has been lost.

The best temperature for the hot air varies with the kind and dimensions of timber. Thus for

	Deg. Fahr.
Hard wood in general—in logs or large pieces ..	90 to 100
Fir wood in thick pieces	120
„ in thin boards	180 to 200

The time for drying varies with the thickness; thus—

Thickness in *inches*	1, 2, 3, 4, 6, 8.
Time required in *weeks*	1, 2, 3, 4, 7, 10.

These periods are fixed on the supposition that the process is carried on during twelve hours per day only instead of twenty-four.*

Another method for which a patent was taken out by M. Guibert is said to give better and more certain results than those obtained from the use of dry and hot air.

It consists of filling the drying oven with smoke produced by the distillation of such matters as sawdust, waste tan, smiths' coal, &c. By means of a ventilator, ingeniously arranged, a rotatory movement round the logs laid to season is given to the smoke, so as to obtain an average uniform temperature in every part. By this plan, as the distillation of the combustibles is always attended with a considerable discharge of steam, all cracks and splits appear to be prevented.†

* 'Civil Engineer Journal,' vol. xii., p. 310.

† De Lapparent's 'Essay on the Prevention of Decay in Timber.'

456. *Weight of a Cubic Foot of Timber, when Green and when Seasoned.*

From Duhamel's experiments;* reduced to English weights and measures.

Kind of Wood.	Weight of a Cubic Foot Green.	Weight of a Cubic Foot One Year afterwards.
	lbs.	lbs.
Oak of Provence	78·25	68·3
Elm ,, ...	57·14	47·5
Poplar ,, ...	49·68	30·69
Walnut ,, ...	54·43	44·08
Lime ,, ...	45·2	27·96
Beech of Bourgogne	56·25	43·95
White Pine of Provence	53·73	43·93
Norway Pine, dry	..	36·75

The writer of an article on timber, in the 'Encyclopédie Méthodique,' states that the weight of a cubic foot of green oak varies from 62·5 to 66 lbs.; of a cubic foot of seasoned oak, from 53·5 to 58 lbs.; and a cubic foot of very dry oak, from 44·6 to 47·3 lbs.† The timber of very old trees is often much lighter than this. The author has tried specimens from old trees that did not exceed 38·5 lbs. per cubic foot when dry. When the specific gravity is very low it may be safely concluded that it is the wood of an old tree, and that it will be brittle and deficient both in strength and toughness.

Some experiments ‡ have been made on the loss of weight

* 'Transport des Bois,' p. 66, *et seq.*

† Art. Bois, Dict. Architecture, 'Encyclopédie Méthodique.

‡ Mr. Couch's Table is published in Barlow's 'Essay on the Strength of Timber,' and contains much valuable information. Mr. Knowles, in his 'Inquiry, &c.,' has added the following ones on two cubes of oak:—

Weight when felled, 62 lbs.	Weight when perfectly dry, 36½ lbs.
Ditto ,, 68 lbs.	Ditto ,, 41·06 lbs.

Loss of weight, 41·5 per cent.
Ditto ,, 40 per cent.

in seasoning, by Mr. Couch, at the Royal Dockyard at Plymouth, from which the following are taken:—

Kind of Wood.	Weight when felled of a Cubic Foot.	Weight Seasoned of a Cubic Foot.	Shrinkage in Seasoning.
	lbs.	lbs.	
Oak (butt end)	69	47½	$\frac{1}{32}$
Elm	58½	36½	$\frac{1}{44}$
	Weight of a cubic foot when first imported.		
Riga masts	42	40	$\frac{1}{72}$
Pitch Pine, American	47	46¼	$\frac{1}{40}$
Yellow Pine ,, ..	42½	28¾	$\frac{1}{144}$
Spruce ,, ,, ..	33	32¾	$\frac{1}{112}$

To these experiments the following are added, which include some varieties of wood not before tried.

Kind of Wood.	Weight of a Cubic Foot when Green.	Weight of a Cubic Foot Dry.	Loss per Cent.
	lbs.	lbs.	
Oak sap-wood (quercus sessiliflora) ..	67·0	47·07	29·8
Spanish Chestnut	54·68	37·91	30·6
Larch	42·06	30·99	26·0
Walnut	57·5	38·5	33·0
Acacia (robinia pseudo-acacia). ..	51·25	46·76	9·0

We are also indebted to Mr. Wiebeking for some experiments on seasoning timber; and as both the kinds of timber and the times of observation are different from those already noticed, his Table is a considerable addition to our knowledge of this important subject. It is in common with all the other Tables in this work, reduced to English weights and measures.*

* 'Traité contenant une Partie essentielle de la Science de construire les Ponts,' p. 114.

Kind of Wood.	Weight of a Cubic Foot Fifteen Days after the Wood was felled.	Weight of a Cubic Foot after Three Months' Exposure to the Air.	Weight of a Cubic Foot when Dry.
	lbs.	lbs.	lbs.
Oak	58·74	56·18	39·27 to 39·58
Larch	53·63	51·08	38·31
Pine (pinus sylvestris)	51·08	38·31	26·817
Pinaster	52·35	33·2	25·54
Fir (abies picea) ..	33·2	29·37	25·22 to 25·54

Wood, when cut into small pieces, very soon acquires its utmost degree of dryness. Dr. Watson, Bishop of Llandaff, in the month of March cut a piece from the middle of a large ash-tree that had been felled about six weeks, and weighed it; its weight was 317 grains; in seven days it lost 62 grains, or nearly one-fifth of its weight. It was tried again in August of the same year, but had not lost any more of its weight; hence it had become perfectly dry in the short space of seven days. He also found that the sap-wood of oak lost more weight in drying than the heart-wood, in the proportion of 10 to 7.*

Mr. Pontey ascertained that the sap-wood of larch lost two-fifths of its weight in drying.†

Durability of Timber.

457. It must also be remembered, that to give durability to his materials is one branch of the carpenter's art; and that to be defective in this particular is as much to his discredit, as to be unacquainted with the geometrical or mechanical principles of carpentry.

Of the durability of timber in a wet state, the piles of the

* 'Chemical Essays,' vol. iii., p. 21.

† 'Forest Pruner,' p. 88. Mr. Pontey is completely wrong when he supposes his experiments to furnish any rule for the time it would require to season larger pieces.

bridge built by the Emperor Trajan across the Danube is an example. One of these piles was taken up, and found to be petrified to the depth of three-fourths of an inch; but the rest of the wood was little different from its ordinary state, though it had been driven more than sixteen centuries.*

The piles under the piers of old London Bridge had been driven about 600 years, and from Mr. Dance's observations, in 1746, it did not appear that they were materially decayed;† indeed they were found to the last to be sufficiently sound to support the massy superstructure. They were chiefly of elm.

458. We have also some remarkable instances of the durability of timber when buried in the ground. Several ancient canoes have been found in cutting drains through the fens in Lincolnshire, which must have lain there for many ages. In the 'Journal of Science, &c.,' published at the Royal Institution, one of these canoes is described, which was found at the depth of eight feet below the surface of the ground. It was 30 feet 8 inches long, and 3 feet wide in the widest part, and appears to have been hollowed out of an oak-tree of remarkably fine free-grained timber.‡

Also, in digging away the foundation of old Savoy Palace, London, which was built nearly 700 years ago, the whole of the piles, consisting of oak, elm, beech, and chestnut, were found in a state of perfect soundness; as also was the planking which covered the pile-heads. Some of the beech, however, after being exposed to the air for a few weeks, though under cover, acquired a coating of fungus over its surface.§

459. On opening one of the tombs at Thebes, M. Belzoni discovered two statues of wood, a little larger than life, and in good preservation; the only decayed parts being the

* Buffon, 'Preuves de la Théorie de la Terre.'

† Hutton's 'Tracts,' vol. i., p. 119.

‡ 'Journal of Science, &c.,' vol. i., p. 244.

§ 'Ency. Brit.,' art. Dry Rot.

sockets to receive the eyes. The wood of these statues is probably the oldest in existence that bears the traces of human labour.*

A continued range or curb of timber was discovered in pulling down a part of the Keep of Tunbridge Castle, in Kent, which was built about 750 years ago. This curb had been built into the middle of the thickness of the wall,† and was no doubt intended to prevent the settlements likely to happen in such heavy piles of building; and therefore is an interesting fact in the history of constructive architecture, as well as an instance of the durability of timber.

In digging for the foundations of the present house at Ditton Park, near Windsor, the timbers of a drawbridge were discovered about 10 feet below the surface of the ground; these timbers were sound but had become black. Hakewell says, that Sir John de Molines obtained liberty to fortify the Manor-house of Ditton, in 1396; ‡ and it is most probable the drawbridge was erected soon after that time; and accordingly the timber had been there about 400 years.

460. The durability of the framed timbers of buildings is also very considerable. The trusses of the old part of the roof of the Basilica of St. Paul, at Rome, were framed in 816, and were sound and good in 1814, a space of nearly a thousand years. These trusses are of fir. §

The timber-work of the external domes of the Church of St. Mark, at Venice, is more than 840 years old, and is still in a good state.‖ And Alberti observed the gates of cypress to the Church of St. Peter, at Rome, to be whole and sound after being up nearly 600 years.¶

* 'Quarterly Review,' vol. xix., p. 422; or 'Ency. Brit.,' art. Dry Rot.

† King's 'Observations on Ancient Castles,' p. 99.

‡ 'History of Windsor,' p. 329.

§ Rondelet, 'L'Art de Bâtir,' tome iv., p. 168.

‖ Ibid., p. 259.

¶ 'Alberti,' book ii., chap. vi.

The inner roof of the Chapel of St. Nicholas, King's Lynn, Norfolk, is of oak, and was constructed about 500 years ago.*

Daviller states, as an instance of the durability of fir, that the large dormitory of the Jacobins' Convent, at Paris, had been executed in fir, and lasted 400 years.†

The timber roof of Crosby Hall, in London, removed in 1869, was executed about 400 years ago; ‡ and the roof of Westminster Hall, which is of oak, is now above 340 years old.

The rich carvings in oak which ornamented the ceiling of the king's room in Stirling Castle, are many of them still in good preservation. It is nearly 350 years since they were executed, and they remained in their original situation till a part of the roof gave way in 1777, when the whole was removed, and has since been dispersed among the collectors of curious relics of old times.§

Moreton Hall, in Cheshire, where "the staircase winds round the trunk of an immense oak tree," and the building itself is chiefly constructed of wood, has now existed nearly 300 years. ||

And Mr. Britton describes an old house at Islington, constructed chiefly of wood, which he has ascertained to be about 240 years old.¶

461. Other notices of extraordinary durability will be found in the descriptions of the different kinds of wood. But enough already has been collected to show that timber is

* Britton's 'Archit. Antiq.,' vol. iii., p. 58.

† Daviller, 'Cours d'Architecture,' tome ii., art. Bois.

‡ Ibid., vol. iv., p. 137.

§ 'Lacunar Strevelinense,' p. 4. This work is a collection of engravings of the carvings; and some of the borders might furnish useful hints to artists.

|| Britton's 'Archit. Antiq.,' vol. ii., p. 83. ¶ Ibid., p. 85.

very durable where nothing more than ordinary means have been used to render it so; that is, nothing more than judicious selection and good seasoning.

Every permanent support should be formed of a good and sound piece of timber; inferior kinds should be used only for temporary purposes, or where no strain occurs, and where they can be easily renewed without injury to the strength of the building.

Mr. Barrow, in writing on this subject, very judiciously remarks, "that the felling of timber while young and full of vigour, making use of the sap-wood, and applying it to ships and buildings in an unseasoned state, have no doubt contributed to make the disease of dry rot infinitely more frequent and extensive than it was in former times, when our ships were hearts of oak, and when, in our large mansions, the wind was suffered to blow freely through them, and a current of air to circulate through the wide space left between the panelled wainscot and the wall. In those old mansions, which yet remain, and in the ancient cathedrals and churches, we find nothing like dry rot, though perhaps

"perforated sore
And drilled in holes, the solid oak is found
By worms voracious eaten through and through." *

462. In regard to the durability of different woods, the most odoriferous kinds are generally considered to be the most durable; also woods of a close and compact texture are generally more durable than those that are open and porous; but there are exceptions, as the wood of the evergreen oak is more compact than that of the common oak, but not near so durable.

Sir H. Davy has observed that, "in general, the quantity of charcoal afforded by woods offers a tolerably accurate in-

* 'Encyclopædia Britannica,' art. Dry Rot.

dication of their durability; those most abundant in charcoal and earthy matter are most permanent; and those that contain the largest proportion of gaseous elements are the most destructible. Amongst our own trees," he adds, "the chestnut and the oak are pre-eminent as to durability, and the chestnut affords rather more carbonaceous matter than the oak." * But we know from experience, that red or yellow fir is as durable as oak in most situations, though it produces less charcoal by the ordinary process. The following Table of the quantity of charcoal afforded by 100 parts of different woods is added, for the information of the reader:—

Kind of Wood.	Watson.†	Mushet.‡	Proust.§	Rumford §
Oak, dry	22·92	22·6	19	43
Chestnut	..	23·2	..	..
Mahogany	20·82	25·4	..	..
Walnut	26·04	20·6	..	..
Elm	..	19·5	..	43·27
Beech	..	19·9	..	..
Fir	15·62	..	..	44·18
Norway Pine	..	19·2	..	..
Pine	..	..	20	..
Scotch Pine	..	16·4	..	..
Ash	17·71	17·9	17	..
Poplar	..	..	..	43·57
Lime	..	..	..	43·59
Birch	..	17·4	..	..
Sycamore	..	19·7	..	..
Sallow	..	18·4	..	..

In Count Rumford's experiments a longer period was allowed for the process; and, in consequence, his results represent more nearly the real quantities of carbon in each wood than the others. But even according to the common

* 'Agricultural Chemistry,' p. 254, 8vo edit.; p. 221, 4to edit.
† 'Chemical Essays,' vol. iii., p. 27.
‡ 'Philosophical Magazine,' vol. ii., p. 183.
§ Dr. Thomson's 'System of Chemistry,' vol. iv., p. 185.

"Inch-and-half planks of trees from thirty to forty-five years' growth, after ten years' standing in the weather, were examined and found to be in the following state and condition:—

Cedar, perfectly sound.
Larch, the heart sound, but sap quite decayed.
Spruce fir, sound.
Silver fir, in decay.
Scotch fir, much decayed.
Pinaster, quite rotten.
Chestnut, perfectly sound.
Abele, sound.
Beech, sound.
Walnut, in decay.
Sycamore, much decayed.
Birch, quite rotten." *

This shows at once the kinds that are best adapted to resist the weather; but even in the same kind of wood there is much difference in the durability, and the observation is as old as Pliny, "that the timber of those trees which grow in moist and shady places is not so good as that which comes from a more exposed situation, nor is it so close, substantial, and durable;"† and Vitruvius has made similar observations.‡

Also split timber is more durable than sawed timber, for the fissure in splitting follows the grain, and leaves it whole, whereas the saw divides the fibres, and moisture finds more ready access to the internal parts of the wood. Split timber is also stronger than sawed timber, because the fibres being continuous, they resist by means of their longitudinal strength, but when divided by the saw, the resistance often

* 'Annals of Agriculture,' vol. vi., p. 256.
† Pliny, as quoted by Evelyn, 'Silva,' vol. i., p. 87.
‡ 'Vitruvius,' book ii., chap. ix.

On the Causes of Decay in Timber.

464. Timber, when properly seasoned, is strong, tough, and elastic; but it does not long retain those properties. It is generally employed in situations where it is either continually dry, constantly wet, alternately wet and dry, or where it is exposed to heat and continued moisture.

465. *Effect of Continued Dryness.*—Timber that is constantly dry, or affected only by the small quantity of moisture which it absorbs from the air in damp weather, has been known to last for seven or eight hundred years; but, even in this state, time produces a sensible alteration in its properties, for it is found to lose its elastic and coherent powers gradually, and to become brittle. Hence it is unfit to sustain the action of variable loads, though in a state of rest it may endure an immense length of time.

466. *Effect of Continued Wetness.*—The wood of trees in its natural state is a compound substance, having a certain portion of its constituents soluble in water, another part capable of being extracted by alcohol, and the part remaining, after being treated with alcohol, is the pure woody fibre, or lignin, of chemists. After water has extracted all the soluble parts from timber, it is obvious that while the timber continues immersed in water it may remain unchanged for an indefinite period; but if it be taken out and dried, it is found to be brittle and effete; or, to use the workman's expression, "its nature is gone;" and, as Dr. Sloane has observed of oak that had been buried in a wet situation, "it dries, splits,

becomes light, and soon impairs."* But though oak timber taken from bogs is always found to be brittle and in a state of decay, fir from the same bog is often, if not always, in a much sounder state.

467. *Effect of Alternate Dryness and Moisture.*—When timber is exposed to the action of alternate dryness and moisture it soon decays. It has been already noticed that repeated steeping and drying removes a sensible portion of the wood at each operation (see Arts. 451 and 452); and it is evident that at each drying a new portion of soluble matter is formed, which either did not before exist, or which is rendered soluble by a change in its nature. This conclusion is further established by Saussure, who found that wood the most completely freed of its soluble particles furnishes always by maceration in water, with the contact of air, infusions holding extractive matter dissolved.† The effect ot this kind of decay may be observed in weather-boarding, fencing, and in any situation where wood is constantly exposed to the vicissitudes of the weather. When the timber has been thoroughly seasoned, painting or any kind of coating that is capable of resisting moisture is the best means of preserving it from this kind of decay (see Art. 473).

468. *Effect of Continued Moisture with Heat.*—Wood, in common with other vegetable products, when exposed to a certain degree of moisture, and at a temperature not much under 45°, nor too high to evaporate suddenly all the moisture, gradually decomposes. This decomposition is called putrefaction by chemical writers, but is called the "*rot*" in common language. It proceeds with most rapidity in the open air, but the contact of air is not absolutely necessary. Water is in all cases essential to the process; indeed, it is a principal agent in all processes of decomposition.

* Evelyn's 'Silva,' vol. ii., p. 105.

† Dr. Murray's 'System of Chemistry,' vol. iv., p. 321.

As the decay goes on, certain gaseous matters are given out, chiefly carbonic acid gas and hydrogen gas.*

Pure woody fibre, alone, undergoes this change slowly, but its texture is soon broken down, and it is easily resolved into new elements when mixed with substances more liable to change. "Any process," observes Sir H. Davy, "that tends to abstract carbonaceous matter from it must bring it nearer in composition to the soluble principles," and this is done by fermentation.† Hence it is that the sap-wood is of a more perishable nature than the heart-wood; for the sap-wood abounds more in saccharine and fermentable principles, and consequently sooner ferments. Dr. Darwin took part of the branch of an oak tree, cut in January, and divided it carefully into three parts, the bark, the alburnum or sap-wood, and the heart-wood. These were each shaved, or rasped, and separately boiled in water, and then set in a warm room to ferment. The decoction of the sap-wood passed into rapid fermentation, and became acid; but not the others.‡

Duhamel tried some experiments to ascertain the effect of confining the sap in green timber, and found that the pieces thus confined soon exhibited signs of rapid decay; and therefore he strongly recommends a free space for the circulation of air round the ends of joists and beams, instead of building them in the wall.§ Duhamel also tried the effect of covering the external surface of timber with paint, tar, and pitch; and found that it contributed much to the durability of dry or well-seasoned timber, but hastened the decay of green and unseasoned timber.‖

Quicklime, when assisted by moisture, has a powerful

* Dr. Thomson's 'System of Chemistry,' vol. iv., p. 396.

† 'Agricultural Chemistry,' p. 249, 4to edit.

‡ 'Phytologia,' p. 33.

§ 'Transport des Bois,' pp. 52 and 53.

‖ Ibid., p. 60; also Chapman on 'Preservation of Timber,' p. 121.

effect in hastening the decomposition of wood, in consequence of its abstracting carbon. Mild lime (carbonate of lime) has not this effect.* But mortar requires a considerable time to bring it to the state of mild lime ; therefore, bedding timber in mortar, or building it in walls where it will long remain in a damp state in contact with mortar, is very injurious, and often the cause of rapid decay. Wood in a perfectly dry state does not appear to be injured by dry lime; of this we have examples in plastering laths, which are generally found sound and good in places where they have been dry. Lime also protects wood from worms.

Volatile and fixed oils, resins, and wax are equally as susceptible of decay as woody fibre under the same circumstances;† hence we see the impropriety of attempting to protect wood in any situation where the coat of paint, &c., cannot be renewed from time to time; and also, that woods abounding in resinous matter cannot be more durable than others.

Decay sometimes commences in the growing tree, for when it has stood beyond a certain age, decay at the heart has generally made some progress (see Art. 442). This has often been observed in large girders of yellow fir, which have appeared sound on the outside, but by removing some of the binding joists have been found completely rotten at the heart.‡ It is on this account that the practice of sawing and bolting girders is recommended (see Art. 198. Sect. III.).

It is usual to divide the rot into two kinds, the *wet rot* and the *dry rot*. The former may take place while the tree is standing, whereas the latter takes place only when the wood

* 'Agricultural Chemistry,' p. 278. † Ibid., p. 238.

‡ The author observed an instance of this kind in the repairs at Kenwood (the seat of the Earl of Mansfield) in 1815; and similar ones at some other places since that time.

is dead. Any part of the substance of a tree or piece of timber may be affected with the wet rot, whereas the dry rot commences chiefly in the alburnum or sap-wood, and is most rapidly developed in warm, moist situations, where the ventilation is imperfect. It is said that the decay of a post placed in the ground, or in water, is an example of the wet rot; and it is sometimes assumed that the parts undergoing the process of decay are alternately wet and dry; but the fact is, they are constantly supplied with that degree of dampness which is essential to putrefaction. For "timber being composed longitudinally of an assemblage of pipes or tubes, it is only necessary that one end of a log of wood should be placed in a damp or wet situation, to occasion the moisture to be conveyed to the opposite end by capillary attraction."* Prevent a free change of atmospheric air, and a post so circumstanced, it is well known, would be affected with the dry rot; otherwise it is not easy to discern any real difference between these two modes of decay.

When the external part of a beam only has been seasoned, and the sap has never been evaporated from the internal part, the rot will be an internal disease; and where an internal decay of this kind is found, it proves that the timber has never been properly seasoned. Mr. Bowden, in the plate to his 'Treatise on the Dry Rot,' gives figures of such a piece; it appears to be of common occurrence; and it is evident from such examples of decay, that the want of due time and attention in seasoning is one of the chief causes of the rapid decay of ships. In Mr. Bowden's specimen the exterior part, to the depth of 2 inches from the outside, was as sound as any wood could possibly be; but the central part was filled with a fine, white, thread-like vegetation, extending within the above-mentioned 2 inches of the exterior surface, and uniting

* 'Encyclopædia Britannica,' art. Dry Rot.

in a thick coat of fungus at the end of the piece,* thus showing the depth to which the timber had been seasoned.

469. When the decay is owing to dry rot the timber at first swells, changes colour, and emits a musty smell. Soon a quantity of white cottony fibres will be found to have penetrated the tissues of the wood, this is the "mycelium" or rootlets of a fungus which derive their nourishment from the wood, and spreading rapidly, collect on the surface into a fine delicate thread-like vegetation, and if a sufficient quantity of heat and moisture be present, they soon form into a compact mass, which ultimately becomes a moist fleshy substance, called the "pileus," of a ferruginous yellow colour, the margin of which is tumid or swollen, downy and white, the folds broad porous and toothed on the surface; lining the sides of the pores of these toothed folds are found the "spores," the dissemination of which reproduces the parent plant. This fungus is known as the *Merulius lacrymans* of the order *Polyporei*, or pore-bearing fungi, so called to distinguish them from the *Agaricini*, or gill-bearing fungi, to which order the common mushroom belongs. The pileus of the *Merulius lacrymans* varies from a few inches to several feet in length and breadth, and is usually found dripping with moisture.

Polyporus destructor is another species found on timber affected with dry-rot; it resembles *M. lacrymans*, but the pileus is neither so fleshy nor so watery, although more fragile.

Oak timber is chiefly attacked by another species called *Polyporus hybridus*, in which the mycelium attains great density and capacity for moisture.

In the more advanced stages of decay the wood contracts lengthwise, and shows many deep fissures across the fibres, similar to a piece of wood scorched by fire. The woody fibres, however, appear to retain their natural form, but easily crumble

* 'Treatise on the Dry Rot,' pp. 11 and 15.

into a fine powder. In oak this powder is of a snuff-brown colour.

The fungus, when it spreads upon the surface of the wood, often becomes of a considerable size, sometimes spreading over the adjoining walls, and ascending to a considerable height.

The decayed state of a barn floor is thus described by Mr. B. Johnson:—"An oak barn floor which had been laid twelve years began to shake upon the joists, and on examination was found to be quite rotten in various parts. The planks, 2½ inches in thickness, were nearly eaten through, except the outside, which was glossy, and apparently without blemish. The rotten wood was partly in the state of an impalpable powder, of a snuff colour; other parts were black, and the rest clearly fungus. No earth was near the wood."*

470. In timber of the same kind, that of the most sappy and rapidly grown trees is the most liable to decay. The wood of trees from the close forests of Germany or America is more subject to it than that of trees grown in more open situations; and it is remarked by Mr. Barrow, that "the timber brought from America in the heated hold of a ship, is invariably covered over, on being landed, with a complete coating of fungus."† Very few cargoes of timber in the log come from America, in which the commencement of the vegetation of the dry rot is not perceptible in some part of each log. Sometimes it will show itself only in a few reddish, discoloured spots on the surface of the log, which, if scratched with the nail, the texture of the timber to a slight depth will be found destroyed, and generally a white fibre will be seen growing on these spots. The red wood timber is less subject to dry rot than the yellow, owing to its containing more turpentine. If the cargo has been shipped in a wet condition, and the voyage has been a long one, a white

* 'Transactions of the Society of Arts,' &c, vol. xxi., p. 294.

† 'Encyclopædia Britannica,' art. Dry Rot.

fibre will most likely be seen growing over nearly every part of the surface of each log, and in cargoes that have been so shipped, all the logs of yellow pine, red pine, and oak, are generally more or less affected on the surface.* It is, therefore, most probable that timber is infected with the seeds of decay before it is brought into use. The custom of floating timber in docks and rivers also injures it very much; it would be better to sink it completely under water, as partial immersion is the worst situation it can be placed in.

471. Though moisture is essential to the progress of decay, absolute wetness will prevent it, especially at a low temperature. In ships this has been particularly remarked, for that part of the hold of a ship which is constantly washed by the bilge-water is never affected by dry rot.† Neither is that side of the planking of a ship's bottom which is next the water often found in a state of decay, even when the inside is quite rotten, unless the rot has penetrated quite through from the inside.‡

472. Warmth and moisture are the most active causes of decay, and provided the necessary degree of moisture is present, the higher the heat the more rapid is its progress. In warm cellars, or close confined situations where the air is filled with vapour without a current to change it, decay proceeds with astonishing rapidity, and the timber-work is destroyed in a very short time. The bread-rooms of ships, behind the skirtings and under the wooden floors of the basement stories of houses, particularly in kitchens, or other rooms where there are constant fires; and, in general, in every place where wood is exposed to warmth and damp air, the dry rot will soon make its appearance, and if the building be inhabited, will also show itself in the altered health of the occupants.

* T. A. Britton: Paper read before the Archit. Association, 1866.

† Bowden's 'Treatise on Dry Rot,' p. 62.

‡ Ibid., p. 68.

473. All kinds of stoves are sure to increase the disease if moisture be present. The effect of heat is also evident from the rapid decay of ships in hot climates.* And the warm moisture given out by particular cargoes is also very destructive; such as cargoes of hemp,† pepper, and cotton.‡

474. Building timber into new walls is often a cause of decay, as the lime and damp brickwork are active agents in producing putrefaction, particularly where the scrapings of roads are used instead of sand for mortar. Hence it is that bond-timbers, wall-plates, and the ends of girders, joists, and lintels, are so frequently found in a state of decay. The old builders used to bed the ends of their girders and joists in loam, instead of mortar, as directed in the act of parliament for rebuilding the city of London.§ In this place it may not be amiss to point out the dangerous consequences of building walls so that their principal support depends on timber. The usual method of putting bond-timber in walls is to lay it next the inside; this bond often decays, and of course leaves the wall resting only upon the external course or courses of bricks; and fractures, bulges, or absolute failures are the natural consequences. This evil is in some degree avoided by placing the bond in the middle of the wall so that there is brickwork on each side, and avoiding the use of continued bond for nailing battens or other fixtures to.‖

But if the powerful lateral pressure of flat arches were avoided, so many ties or bond-timbers would not be necessary. The improper use of arches produces more fractures in buildings than any other cause. Nothing can be more

* Bowden's 'Treatise on Dry Rot,' p. 70.

† Chapman on 'Preservation of Timber,' p. 14.

‡ Ibid., p. 73.

§ 19 Car. II., cap. 3.

‖ In bad foundations it is sometimes the practice to build on a platform of timber; but unless this platform be continually wet, the timber is certain to decay, which will allow the walls to settle, and probably rend the building to pieces. Instances of this kind are by no means

outwards at the base. In 1729 a large crack and several smaller ones were observed in the dome. On examination the wooden curb was found to be in a completely rotten state, and it was necessary to raise a scaffold from the bottom to secure the dome from ruin. After it was secured from falling, the wooden curb was removed, and a course of stone, with a strong band of iron, was put in its place.*

The bad effects resulting from damp walls is still further increased by hasty finishing. To enclose with plastering and joiners' work the walls and timbers while they are in a damp state, is the most certain means of causing the building to fall into a premature state of decay.

rare; it was found necessary to underpin, at immense cost, three of the large houses in Grosvenor Place, London, which had settled from this cause. In one of the houses the floors were not less than three inches out of level. The wood platform, which was of yellow fir, seven inches thick, was found completely rotten. A similar accident happened at Norfolk House, St. James's Square, where oak planking had been used.

* Rondelet, 'L'Art de Bâtir,' tome iv., p. 256; or 'Encyclopédie Méthodique,' Dict. Architecture, art. Coupole.

475. There is another cause that affects all wood most materially, which is the application of paint, tar, or pitch, before the wood has been thoroughly dried. The nature of these bodies prevents all evaporation, and confines the internal moisture, which is the cause of sudden decay. Mr. Bramley remarks, that both oak and fir posts were brought into a premature state of decay by their having been painted prior to a due evaporation of their moisture,* and painting affords no protection to timber against dry rot.

On the other hand, the doors, pews, and carved work of many old churches have never been painted, and yet they are often found to be perfectly sound, after having existed above a century.† In Chester, Exeter, and other old cities, where much timber was formerly used, even for the external parts of buildings, it appears to be sound and perfect, though black with age, and has never been painted.

Semple mentions an instance of some field-gates made of home fir, part of which, being near the mansion, were painted, while the rest, being in distant parts of the grounds, were not painted. Those which were painted soon became quite rotten, but others that were not painted continued firm.‡

Painted floor-cloths are very injurious to wooden floors, as they soon cause decay by preventing the access of atmospheric air and by retaining whatever dampness the boards may absorb. Carpets are not quite so injurious, but still they assist in retarding free evaporation.

476. *Destruction of Timber by Marine Animals.* — The bottoms of ships, piles, and other timbers exposed to the action of the sea, are liable to be destroyed by marine animals, which attack them in every vulnerable part within their reach.

* 'Transactions of the Society of Arts,' &c., vol. xxi., p. 302.

† Rees's 'Cyclopædia,' art. Timber.

‡ 'Treatise on Building in Water.'

The most destructive of these belong to the classes Conchifera and Crustacea. Of the former is the well-known ship worm *Teredo navalis*, and of the latter are the *Limnoria terebrans* (or *lignorum*) and the *Chelura terebrans*. They bear no resemblance to each other.

477. The *Teredo navalis* is first attached to the timber in the form of an egg, which is supposed to be washed against it by the action of the sea. It remains in this state for some time, probably until the salt water has thoroughly penetrated the substance of the wood, and vegetation has commenced to form on its surface. When the animal leaves the egg it is very small, but after entering into the wood it soon increases to a considerable size, often 3 or 4 inches in length, and sometimes a great deal more.

In a fir pile taken from the old pier-head at Southend, a worm was found 2 feet long and $\frac{3}{4}$ inch in diameter, and they have been heard of as much as 3 and 4 feet in length, and 1 inch in diameter, according to the nature of the wood which they inhabit.*

To the casual observer there is frequently no symptom of the destruction that is taking place, apparent on the surface, nor are the animals themselves visible until the outer part of the wood has been cut or broken away, when their shelly habitations come into sight and show the perfect honeycomb they have formed. On a closer examination of the wood, however, a multitude of very minute perforations are discovered in the surface, generally covered with a slimy matter: and on opening the wood at one of these and tracing it, the tail, or posterior portion of the animal, is immediately found, and after various windings and turnings, the head is discovered, which in some cases has been found as much as 3 feet from the point of entrance. Sometimes it will happen, especially if the wood has been much eaten, that

* 'Min. Proc. Inst. of Civil Engineers,' 1849–50.

their shelly tubes are partly visible on the surface, but this is rare; they enter at the surface, and bore in every direction, both with and against the grain of the wood, growing in size as they proceed.

It is rarely that the animal bores completely through, although it frequently approaches to within a twentieth of an inch of the surface.

The head of the *teredo* is provided with a hard calcareous substance, which performs the office of an auger, and enables it to penetrate the hardest wood.

Although these animals often bore exceedingly close to each other, they never injure one another's habitation.

Fir and alder are the two kinds of wood they seem to destroy with the greatest ease, and in which they attain their greatest size.

In oak and other hard woods they make slower progress, are smaller, and do not appear to be so well nourished.

In some situations they carry on their depredations with great rapidity, and the parts of the wood most subject to their attacks are those between the bottom and low water, and they appear gradually to relax in their destructive habits from low water towards high water. Some of the Memel fir piles of the old pier-head at Southend, which had been well coated with pitch and tar previously to being fixed, and parts covered with copper, showed signs of the teredo within six months after the completion of the work, and in twelve months was reported to have been seriously injured, and in four years both it and the Limnoria had eaten some of the piles completely through.

The teredo, it has been said, was originally brought from India, but this is a mistake, as it has been discovered in this country in a fossil state, and its ravages have been known in Scotland for more than 300 years.*

* Stevenson's 'Design and Construction of Harbours.'

It seems, however, to be very abundant in the East and West Indies, on the coast of Africa, and in the Mediterranean. It is said to avoid bitter woods. The "Jarrah" timber of Western Australia has also been known to resist its ravages, and so has the Greenheart timber of British Guiana.

478. The *Limnoria terebrans.*—This animal is much smaller than the *Teredo navalis,* and differs from it in shape, being about one-sixth of an inch in length, and not unlike a grain of rice, whereas the teredo has more the shape of a worm. The *Limnoria* appears to be furnished with mandibles and foot-jaws, with which it tears the softer particles of the wood, entirely avoiding the knots and the harder parts. It prefers to attack fir timber, and is known to destroy beech, but rather objects to teak, whereas the teredo attacks mahogany, teak, and other hard woods. Mr. Stevenson found that Memel timber was destroyed by the *Limnoria* at the Bell Rock at the rate of about *one inch inwards per annum.** It appears to extend its depredations to a higher point above low water than the teredo.

479. The *Chelura terebrans*, or wood-boring shrimp, is another animal of the same class as the Limnoria, but far more destructive, which was detected in timber taken from the sea at Trieste in 1839. It was first observed as an inhatant of the British Seas, several years ago, by Mr. Robert Hall, of Dublin, and in January, 1847, it was described by Mr. Mullins in a paper read before the Institution of Civil Engineers of Ireland, as being very injurious to the timber piles of the jetty in Kingstown Harbour, near Dublin.†

480. Smeaton describes a kind of animal which he had observed in Bridlington piers. The wood of these piers he says is destroyed by a certain species of worm differing from the common worm whereby ships are destroyed. "This

* 'Account of the Bell Rock Lighthouse.'

† 'Min. Proc. Inst. of Civil Engineers,' 1849–50.

worm appears as a small white soft substance, much like a maggot; so small as not to be seen distinctly without a magnifying glass, and even then a distinction of its parts is not easily made out. It does not attempt to make its way through the wood longitudinally or along the grain, as is the case with the common ship worm, but directly, or rather a little obliquely, inward. They do not appear to make their way by means of any hard tools or instruments, but rather by some species of dissolvent liquor, furnished by the juices of the animal itself. The rate of progression," he was informed, "is, that a three-inch oak plank will be destroyed in eight years by action from the outside only."*

Smeaton here evidently describes the *Limnoria terebrans.*

None of these animals can live except where they have the action of the water at every tide, nor do they live in the parts covered with sand.

481. A species of Pholas (*Pholas dactylus*) is another animal which is very destructive, not only to timber but to stones, clay, &c., when submerged in water. It makes its attack in a similar manner to the teredo, by burrowing when young the entrances of the holes being only about one-fourth of an inch in diameter. The animal increasing in size as it advances forms a larger hole, until it arrives at maturity, when it ceases to bore. It derives its sustenance from the water, and never bores so far that it cannot reach the water with its proboscis.†

482. The Lepisma is also a destructive little animal in the East Indies; it begins to prey on the wood as soon as it is immersed in sea water. The unprotected bottom of a boat has been known to be eaten through by it in three or four weeks.

483. The following Table by Mr. Stevenson shows the

* Smeaton's 'Reports.'

† Wilcox, 'Papers on Naval Architecture,' vol. i., p. 154.

result of exposing different kinds of timber to the attacks of the *Limnoria terebrans* at the Bell Rock in 1814, 1821, 1837, and 1843.

TABLE of the RELATIVE DURABILITY of DIFFERENT KINDS OF TIMBER when Exposed to the Attacks of the *Limnoria terebrans.*

Kind of Timber.	Decay first observed from time of exposure.	Unsound and quite decayed.	Quite Sound for	Remarks.
	Yrs. Mon.	Yrs. Mon	Yrs. Mon.	
Greenheart	..	..	19 0	Affected in one corner.
Teak	..	..	13 0	
Beefwood	..	..	13 0	
Treenail of bulletwood	..	..	5 0	
Beech, Payne's patent process	10 7	..	..	A little holed at one end underneath.
Teak	5 6	..	..	Nearly sound 7½ years after being laid down.
African oak	5 6	..	..	Ditto ditto
,, ,, ...	4 11	10 0	..	
English oak, kyanized	4 7	10 0	..	Decaying but slowing 5 years and 7 months after being laid down.
Teak	4 7	12 0	..	
American oak, kyanized	4 3	..	..	
British ash	3 0	5 0	..	
Scotch elm	3 0	5 0	..	
English elm	2 11	4 7	..	
Plane-tree	2 11	..	..	Ditto ditto
Ash	2 11	4 3	..	
American oak	2 11	4 7	..	
Baltic red pine	2 9	4 3	..	A good deal decayed when first observed.
English oak	2 4	4 7	..	
Scotch oak	2 4	..	.	Ditto ditto
Baltic oak	2 4	4 3	..	
Norway fir	2 4	3 1	..	
Baltic red pine, kyanized	2 4	4 7	..	
Pitch pine	2 4	4 3	..	
American yellow pine	2 4	3 7	..	
,, red pine ..	2 4	3 1	..	
,, ,, kyanized	2 4	4 7	..	
Larch	2 4	4 3	..	

TABLE—*continued.*

Kind of Timber.	Decay first observed from time of exposure. Yrs.	Mon.	Unsound and quite decayed. Yrs.	Mon.	Quite Sound for Yrs.	Mon.	Remarks.
Honduras mahogany..	2	1	..		..		Nearly sound 3½ years after being laid down. Washed away 6 months later.
Beech	1	9	3	1	..		
American elm	1	9	3	1	..		
Treenail of locust ..	..		5	0	3	0	
British oak..	1	6	5	0	..		
American oak	1	6	5	0	..		
Plane-tree	1	6	5	0	..		
Honduras teak treenails	1	6	5	0	..		
Beech	1	6	5	0	..		
Scotch fir, teak treenails	1	6	3	0	..		
Ditto, from Lanarkshire	1	6	3	0	..		
Ditto ditto ..	1	6	3	0	..		
Ditto, locust treenails	1	6	3	0	..		
Memel fir	1	6	5	0	..		
Pitch pine	1	6	2	6	..		Going fast when first observed.
English oak	1	1	3	1	..		
Italian oak	1	1	3	6	..		
Dantzic oak	1	1	2	6	..		
English elm	1	1	1	6	..		
Canada rock elm ..	1	1	1	6	..		
Cedar of Lebanon ..	1	1	2	6	..		
Riga fir	1	1	1	6	..		
Dantzic fir	1	1	1	6	..		
Virginia pine	1	1	1	6	..		
Yellow pine	1	1	1	6	..		A good deal gone 18 months after being laid down. Swept away by the sea 7 months afterwards.
Red pine	1	1	1	6	..		
Cowrie pine	1	1	1	6	..		A good deal decayed when first observed.
Polish larch	1	1	1	6	..		Going fast when first observed.
Birch, Payne's patent process	0	10	1	10	..		
American locust treenails	0	8	3	0	..		

484. *Destruction of Timber by Ants.*—Of the ant proper, or that belonging to the order Hymenoptera, called the carpenter ant, there are three species in particular which attack timber, *viz.* the *Formica fuliginosa*, or black carpenter ant; the *Formica fusca*, or dusky ant; and the *Formica flava*, or yellow ant.

The first prefers hard and tough wood, whereas the other two prefer soft wood. The carpenter ant, though not very destructive to seasoned wood, has been known to destroy standing timber. Wood, when attacked by the *Formica fuliginosa*, or black ant, is tinged of a black colour, supposed to arise from iron in its saliva acting on the gallic acid of the timber.

485. One of the most destructive insects to which timber is exposed in tropical climates is the larva of that known as the White Ant, a species of Termite of the genus *Termes*, belonging to the order Neuroptera. It has very little affinity with the carpenter, or true ant, being a rather disagreeable-looking insect, not quite a quarter of an inch long, having a body about four-fifths of the full length, of a cream colour, very soft and fatty in substance.

It has a head of a dark brown colour, pointed and protected by a thin shell, or hard covering, with two short mandibles.

The body is supported on short dark-coloured legs, which move very rapidly, while the insect itself advances about 2 inches in a second.

The white ant is found both in Africa and the East Indies, as well as in the Mauritius and St. Helena, besides other colonies situated in the Tropics. The African species, *T. fatalis*, is said to be the most formidable.

According to a well-written paper by Mr. Thomas Hounslow, of the Royal Engineer Department, published in 'Engineering of 21st September, 1866; the white ants will destroy the timber-work of a house, without noise; and fre-

quently, as they never destroy the surface of the wood, without giving the slightest indication of the mischief they are doing. They will eat out the whole of the interior wood, leaving a thin shell of the surface untouched; and in the case of wood that has been frequently painted they will sometimes devour nearly the whole of the wood, leaving only the paint supported here and there by a thin splinter.

The first indication of an attack on the wood-work of a house might be the yielding of a flooring board in the middle of a room, or the top hinge of a door suddenly leaving the frame to which it had been firmly screwed a short time before. In two or three days they will eat a large box full of paper, so as to render it valueless; and at the end of a week they will reduce the whole to a mass of dark-brown dirt.

Teak is said to be almost the only wood the white ants will leave unmolested.* The "Jarrah" timber of Australia is also said to escape their ravages, though they sometimes pierce the sap, or outer wood; but the red timber which constitutes the main body of the tree has not been attacked.

Some experiments were made at St. Helena between the years 1863 and 1866, by order of the Lieutenant-Governor, to ascertain the kind of wood, or the best means of preparing wood, to resist the white ant. Specimens of all kinds of American and European pines, both red, white, and pitch-pine, oak, cedar, ash, elm, beech, birch, mahogany, teak, and a specimen of Jarrah wood from Australia, were placed in situations where they would be most liable to the attack of the ant. Some specimens of the native pine, or fir of St. Helena, and some of oak, elm, and ash, were chemically prepared—one series, by merely washing over the surface with three or four coats of a poisonous solution prepared from

* It is probably some essential oil with which the teak is impregnated that prevents their touching it, as they have been known to eat it when the timber is old and has long been exposed to the air.

sulphate of copper and chloride of zinc; and another series, by injecting the solution into the pores of the wood, the natural juices having been first thoroughly expelled.

Specimens of wood, which had been saturated with corrosive sublimate, chloride of zinc, creosote, salts of lead, and even carbolic acid, were sent from England for trial. At the end of twelve months it was found that the unprepared samples of pine-wood had completely disappeared, and most of the others were reduced to something between a cinder and a sponge in appearance. The Jarrah wood, though attacked severely, was only partially destroyed; but the teak remained in every instance sound and uninjured.

Kæmpfer, speaking of the white ants of Japan, gives a remarkable instance of the rapidity with which these insects proceed. Upon rising one morning, he observed that one of their galleries, of the thickness of his little finger, had been formed across his table; and upon a further examination, he found that they had bored a passage of that thickness up one leg of the table, formed a gallery across it, and then pierced down through another leg into the floor; all this was done in the few hours that intervened between his retiring to rest and his rising.*

The Preservation of Timber.

486. The presence of moisture being one of the conditions which appear to be necessary for the decomposition of organic substances, it is desirable that the neighbourhood of buildings where timber is used should be well drained, which not only prevents decay, but tends to preserve the health of the occupants.

Drains should be made water-tight when they come near to walls, particularly those built of bricks, which readily absorb

* 'Japan,' vol. ii., p. 127.

moisture, and conduct it to a considerable distance. Earth or soil liable to become damp should never be permitted to rest against the walls of buildings; and when the lowest or basement story is sunk, the building should be surrounded by a dry or open area.

487. The moisture should be prevented rising from the foundation by interposing a layer of some impervious substance through the thickness of the wall, at a height of several inches above the ground. Sheets of lead or copper have been used for that purpose, but as they are expensive, two or more courses of slates that do not readily absorb moisture, laid in Portland, Roman, or some kind of bituminous cement, have been substituted, with a layer of the cement spread over the upper surface.

A very perfect damp-proof course is formed by spreading a thin layer of asphalte—say about $\frac{3}{8}$ or $\frac{1}{2}$ inch thick—throughout the thickness of the wall: the best position for it is on the top of the course which is immediately under the wood sleepers that support the ground joists.

A very good description of damp-proof course is that formed of glazed earthenware, known as "Taylor's Damp-proof Course," when properly laid in a cement that is impervious to moisture.

Whatever kind of damp-proof course be used, care should be taken to prevent its being broken or fractured by the weight of the work placed above it.

Rendering or weather-slating the outside vertical surface of walls is also a good expedient to keep out damp, and so preserve any wood that may be in contact with the masonry of the building.

488. After a building is covered in, and before the doors and sashes are hung, the walls and principal timbers should be left for some time to dry, which will also enable the latter to settle to their proper bearings, and so prevent cracks from

appearing in the plastered ceilings and partitions, the execution of which should be deferred until after the timbers have ceased to shrink or settle.

Timber should not, however, be left to season until after it is fixed, but the fact of its imbibing a certain quantity of moisture from the damp walls of the building (which causes it to swell), renders some amount of shrinkage afterwards, on drying, unavoidable.

A considerable time should also be permitted to elapse after the plastering is finished to allow of the work becoming dry again, before the floors, skirtings, and other joiner's work be fixed.

When a building has been thoroughly dried at first, openings for the admission of fresh air are not so much required as where the precautions against fresh accessions of moisture have been neglected. Indeed, such openings in the walls of a building, when sufficiently large to be of use in preserving the woodwork, are frequently a source of discomfort to the occupants, from the difficulty of regulating the supply of air which passes through them. In many situations—as under the floors of a basement story, particularly when the openings are small—it is difficult to obtain a sufficient current of air to carry off any considerable quantity of moisture; consequently, we find that the timber of floors in such situations is more liable to decay than that in roofs. And Mr. Papworth observes: "Should the air absorb less moisture from the fungus than the timber affords to its vegetation, the air will then increase the disease, and draw into fuller growth the fungus it has not the power to destroy; but if dry air be admitted in a quantity adequate to cause that absorption, it will necessarily exhaust and destroy the fungus." * From which it would appear that a small quantity of air may do more harm than good.

* 'Essay on the Causes of the Dry Rot,' p. 43.

489. In floors next the ground the access of damp should be prevented as much as possible by careful drainage and the removal of all vegetable mould from the surface, and, where possible, a layer of concrete or a considerable thickness of dry materials, such as brickbats, dry ashes, &c., but not lime, should be laid under the floor, and over these a coat of smith's ashes, or of pyrites, where they can be procured. The timber for ground-joists and sleepers should be particularly well seasoned; and it is advisable to cut off all connection between the wooden ground-floors and the other woodwork of the building.

490. Well-seasoned timber is likely to last for a long time unless placed in situations that are favourable to putrefaction; and as such situations cannot always be avoided, various remedies have been suggested with the view of retarding the process of decay. None of them have met with more than a partial success, and many of them have been complete failures.

491. *Oil paint* is most commonly used for the protection of timber when exposed to the weather. It forms an impervious coat on the surface, and prevents the moisture from penetrating to the wood; but if the timber has not been previously well seasoned, the application of paint will rather promote than retard the process of decay, by preventing the evaporation of the juices of the wood, which ferment and putrefy.

For timber that is not exposed to the weather the utility of paint is somewhat doubtful; in joiners' work, where it is usually cut into thin slabs or small scantlings, which ensures it a better seasoning, paint may be of some use in preventing the wood from cracking, as it retards the evaporation of any moisture that may have remained in it.

Wood used in out-door work should have those parts painted only where moisture is likely to find a lodgment, and

492. *Coal-tar*, when deprived of a portion of its naphtha by boiling, is a valuable protection to timber exposed to the weather; but in order to give it "body," dry chalk powdered fine is frequently mixed with it.

The Dutch, for the preservation of their gates, sluices, drawbridges, and other large works of timber exposed to the weather, coat them with a mixture of pitch and tar, upon which they sprinkle small pieces of cockle and other shells, ground almost to a powder, and then mixed with sea-sand, or the scales of iron beaten small and sifted.†

Semple describes a method of protecting timber from the effects of the weather, by thoroughly heating, and even scorching it all over, and while hot, applying linseed oil and tar which have been well boiled together and kept boiling while being applied. He says that if the wood be tolerably well seasoned, the mixture will sink into the wood one inch or more, and, by closing all the pores, make it exceedingly hard and durable.‡

Vegetable tar, which is obtained from pine timber, is

* 'Preservation of Timber,' p. 147.

† Evelyn's 'Silva,' vol. ii., p. 219.

‡ 'Building in Water,' p. 85.

thought by some to be preferable to coal-tar, in consequence of its being less evanescent.

493. *Silicate of Soda* in solution has been recommended by Mr. Abel, the eminent chemist to the War Department, as giving to wood, when applied to it like paint, a hard coating which is durable for several years, and is also a considerable protection against fire. The silicate of soda, which is prepared for use in the form of a thick syrup, is diluted in water in the proportion of 1 part by measure of the syrup to 4 parts of water, which is added slowly, until a perfect mixture is obtained by constant stirring. The wood is then washed over two or three times with this liquid by means of an ordinary whitewash brush, so as to absorb as much of it as possible. When this first coating is nearly dry, the wood is painted over with a wash made by slaking good fat lime diluted to the consistency of thick cream. Then, after the limewash has become moderately dry, another solution of the silicate of soda, in the proportion of 1 part by measure to 2 parts of water, is applied in the same manner as the first coating. The preparation of the wood is then complete; but if the lime coating has been applied too quickly, the surface of the wood may be found, when quite dry after the last coat of the silicate, to give off a little lime when rubbed with the hand; in which case it should be once more coated over with a solution of the silicate of the same strength as in the first operation.

494. *Common Salt* (muriate of soda) is found to protect timber when the proportion of salt is considerable. The large wooden props which support the roofs of the salt-mines in Hungary, and which are perpetually moistened with salt-water trickling down them, are said to last for centuries;* and the timber of vessels employed in carrying salt fish are preserved for a great number of years by the incrustations

* Darwin's 'Phytologia,' p. 520.

of salt upon them.* The use of salt for preserving timber is objectionable in most situations, owing to its affinity for moisture.

Timber has been cleared of fungus by immersing it for several months in sea-water. A ship called the 'Eden' was cleared of every trace of fungus by remaining eighteen months under water.†

It is known, however, that a *small* quantity of common salt rather assists the decomposition of vegetable matter than otherwise.

495. *Sulphate of Iron* (commonly called green copperas) has been thought of to prevent decay. Wood becomes so hard and compact when boiled in a solution of it, and kept for some days in a warm place to dry, that moisture cannot penetrate it. In the 'Swedish Transactions' it is recommended for preserving the wood of wheel carriages.‡

Chapman observes that the wooden vessels in which copperas is crystallized become exceedingly hard, and are not subject to decay. He also recommends that timber for shipbuilding should be immersed in a solution of the salt.

Sulphate of iron is the principal substance used in the process patented by Mr. Payne in 1841, which consisted in using two solutions in succession, which mutually decompose each other, and form an insoluble substance in the pores of the wood, one being sulphate of iron, and the other carbonate of soda. The first is introduced into the timber under pressure, then drawn off, and the latter forced in, the combination formed in the cellular vessels of the wood by the process being oxide of iron. The process has been extensively adopted, and with tolerable success where well performed.

* Bowden on 'Dry Rot,' p. 162.

† 'Trans. of the Soc. of Arts,' vol. xxxvi., p. 54.

‡ Neuman, quoted by Chapman 'On Preservation of Timber.'

Dr. Darwin, many years before Payne obtained his patent, suggested soaking timber in lime-water, and afterwards, when dry, in a weak solution of sulphuric acid in water, with the view of forming a compound of sulphate of lime in the pores of the wood, but it does not appear to have been of any practical utility; sulphate of lime being soluble in water, the timber is required to be kept dry.*

Boiling in alkalies has been proposed; but as the alkalies dissolve and decompose the woody fibre,† the process cannot be attended with advantage.

496. Quicklime, when present in small quantities and aided by moisture, assists putrefaction; but where present in large quantities, so as to preserve the wood in a perfectly dry state, by absorbing the moisture, it hardens the sap and renders the wood durable. Chapman states that vessels employed in the Sunderland lime trade were very sound, though some of them were forty years old.‡

497. In 1737 the first patent was obtained by Alexander Emerson for a method of preserving timber with *boiled oil*, mixed with poisonous substances, applied hot. Since that time numerous patents have been taken out, but we shall limit our description to those which have obtained the most success and proved the most effective.

498. Kyan's patents were obtained in 1832 and 1836 for the preservation of wood and other vegetable substances by soaking them in a solution of *corrosive sublimate* (bi-chloride of mercury), which in the case of wood forms a new chemical compound, with the albumen, and prevents the destructive power going on. At first the proportion used was 1 lb. of corrosive sublimate to 4 gallons of water; but on subsequent

* 'Phytologia,' p. 519.

† Dr. Thomson's 'Chemistry,' vol. iv., p. 183.

‡ 'Preservation of Timber,' p. 16.

trials it was found that the wood absorbed about 6 or 7 lbs. of the salt per load, which would have rendered the process too costly for general use. Ultimately the proportions were reduced to 1 lb. of corrosive sublimate to 10 gallons of water when a maximum strength was required, and 1 lb. to 15 gallons of water when a minimum; with the latter proportion, 1½ lb. was sufficient for a load of timber containing 50 cubic feet.

The solution was contained in a wooden tank, put together, so that no metal of any kind could come in contact with it. The salt dissolves best in tepid water. The time required to saturate the timber depends on its thickness. Twenty-four hours are usually allowed for each inch in thickness of boards and small timber. Large timber requires from a fortnight to three weeks.

So highly was this patent thought of that in 1833 it formed the subject of a lecture delivered by Professor Faraday at the Royal Institution, and in 1836 was reported most favourably of by the authorities of the Royal Carriage Department at Woolwich. In 1838 the Dutch Government adopted it in the Royal Navy, after obtaining the report of a commission appointed to inquire into its merits, and who made numerous experiments.

After a time the patent fell into the hands of a company, and the process was, in many cases, imperfectly carried out. Notwithstanding that corrosive sublimate is highly destructive to all forms of animal life, Kyan's process has not been found effective either against the worm or white ant, though it appears to have had some effect in retarding the dry rot. It is now, however, seldom used.

499. In 1837 Margary obtained a patent for preserving timber, ropes, canvas, and other substances, by soaking them in a solution of acetate, or sulphate of copper; but the only advantage which this process had over that introduced by

Kyan was in the comparative cheapness of the salt used; and it appears to have failed even more completely in practice. Several of the sleepers on the Bristol and Exeter Railway which had been prepared according to Margary's patent were found decayed after a short time, and had to be removed.

500. The next patent which attracted public notice was taken out in 1838 by Sir William Burnett, who was Director-General of the Medical Department of the Navy, and had for its object, in common with Kyan's, Margary's, and Payne's processes, the coagulation of the albumen of the wood. He used, in a wooden tank, a solution of *chloride of zinc*, in the proportion of 1 lb. to 4 gallons of water for timber, and 1 lb. to 5 gallons of water for canvas, cordage, &c.

Timber requires to be immersed for about two days for each inch in thickness, and afterwards taken out and left to dry from fourteen to ninety days.

Canvas, ropes, &c., require to be immersed in the solution for about forty-eight hours, and then taken out and dried. The process on wood may be more expeditiously performed by means of the hydraulic press, with which the solution of chloride of zinc is forced into the timber. The system has been introduced into several of the Government dockyards; and where the timber can be kept tolerably dry, it is no doubt beneficial, as it tends to harden the wood and renders it partially incombustible. It is also supposed to prevent the attacks of insects, which are found to commit great ravages in the interior fittings of vessels.*

501. It appears that one of the most successful means yet tried of preserving timber, whether from the effects of exposure to the weather, dry rot, or the attacks of worms and insects, is by impregnating its substance with the oil of tar, called *creosote*, which is one of the products obtained from

* 'Min. Proc. Inst. C. E.,' 1852–3.

the distillation of coal-tar, and possessing powerful antiseptic properties. When injected into the wood creosote has the effect of coagulating the albumen, thereby preventing decomposition, and the bituminous oil with which it is combined enters the capillary tubes of the wood, closing up its pores so as to exclude both air and moisture, and the noxious properties of the oil has the effect of repelling both worms and insects.

Several attempts have been made from time to time to introduce this substance into notice, as a preservative of wood; and although it has been used in one form or another since the time of the Egyptians, as seen in the mummy cases, some of which have remained sound to this day, it was not until Mr. Bethell obtained his patent in 1838 that it became extensively used. The opinions of engineers, who have used it for the preservation of railway sleepers in all climates, both at home and abroad, have been strongly in its favour, and its power of enabling timber to resist putrefaction, and to a considerable extent of repelling the attacks of the sea-worm and white ant, when properly applied and in sufficient quantity, has been placed beyond doubt.

It was found, however, by Mr. Stevenson to have failed in repelling the attacks of the *Limnoria terebrans* at Invergorden in Scotland, where the piles of a jetty, erected in 1858 and which had been thoroughly creosoted, "were very much eaten and perforated" in about four years after being fixed; and Mr. Stevenson, in a paper "On the Ravages of the *Limnoria terebrans*," read before the Royal Society in 1862, gave it as his opinion that the process of creosoting preserved timber from the attacks of marine insects, only so long as the oil existed as a film, or coating, on the outside of the timber. When the attrition caused by the motion of the sea removed this film or coating, and exposed the fibrous surface of the timber, the insects would then attack and per-

forate it, whether it was creosoted or not, its search being for a fibrous substance in which to burrow.*

The mode of impregnating wood with creosote adopted by Mr. Bethell is to dry out all the moisture from the pores of the timber, by passing all the smoke and products of combustion from the burning fuel through the drying-house so as to pass between the different pieces of wood, thereby drying and smoking them at the same time, after the manner that hams, bacon, and fish are smoked and cured. By this mode of drying, wood that has been cut down for several months loses in ten hours about 8 lbs. in weight per cubic foot; and if immersed in hot creosote oil in open tanks directly after it leaves the drying-house, and while warm, it quickly absorbs the oil to the extent of 8 or 9 lbs. per cubic foot. Another method is to place the timber (after it leaves the drying-house) in a wrought-iron cylinder with closed ends, and to force in the heated oil at a pressure of about 170 lbs. to the square inch. The heat is kept up in order to prevent the creosote from crystallizing in the pores of the wood during the process. Under this system, pine, fir, or other soft wood easily absorbs from 10 to 12 lbs. of oil per cubic foot. For railway works, Mr. Bethell considered 7 lbs. per cubic foot sufficient, but for marine works he recommended that 10 lbs. of the oil per cubic foot, at least, should be forced into the wood, and some engineers have required even 12 lbs. Into oak and other hard woods, particularly those of India, it is sometimes difficult to force more than 2 or 3 lbs. of the oil, even by the heaviest pressure.† The Saul-wood of India was seldom penetrated more than $\frac{1}{8}$ of an inch from the surface.

502. Another method which is applicable to the preservation of straight-grained or porous timber was introduced some years ago by M. Boucherie, a French chemist. Instead

* 'Civ. Eng. and Arch. Journal,' vol. xxv., p. 206.

† Tract on Bethell's 'Improvements in Preserving Timber,' 1850.

of using great pressure to impregnate the timber, as in creosoting, he applied a moderate pressure only to one end of the log or tree, which had the effect of expelling the sap, and permitted the pores of the timber to be filled with the pre-

There are certain kinds of timber which are impenetrable by the solution applied in the manner described. It answers best with newly-felled beech, birch, larch, Scotch pine, alder, elm, poplar, &c. Trees felled any time between November and May can be prepared in the latter month, but when cut down in May, or any month between that and November, they should be prepared within three weeks of the time of felling.

It was found, during the preparation of vast quantities of timber for the French navy and railways, that the time necessary for the operation depends both on the length of the tree and on the description of timber. Trees of 40 feet in length, prepared at Fontainebleau for the French navy,

required from eight to ten days to become sufficiently impregnated; whereas for a length of 9 feet only, the process was accomplished in twenty-four hours. One great advantage attending M. Boucherie's method is the small cost of the apparatus required.

M. Boucherie also used the impure pyrolignite of iron, which was found not only to preserve the wood from decay, but to harden it to a very high degree.

503. *To Cure the Dry Rot.*—When once this disease has set in, the cure is very difficult, as the whole place where the timber is situated becomes infected. Measures should be immediately taken to provide proper ventilation, and to cut off the access of moisture; the diseased parts of the timber should be cut away, and every particle of fungus removed by brushing the walls and adjoining timbers; after which a wash should be applied to all infected places, consisting of some solution that will destroy any germs of fungi that may have escaped the brush.

Sir H. Davy proposed corrosive sublimate, which should not be of less strength than 1 ounce to every gallon of water, laid on hot.

A solution of sulphate of copper, in the proportion of about 8 ounces to a gallon of water, is said to make an excellent wash, and is cheaper than the corrosive sublimate.

A mixture of sulphate of copper and sulphuric acid in the proportion of 1 lb. of each to 6 gallons of water has been found to preserve timber for nearly double the ordinary period. The sulphate of copper should first be dissolved in 1 gallon of boiling water, and the remainder of the water and sulphuric acid added afterwards.*

Sulphate of iron has been used as a wash for timber, but it is not so efficacious as sulphate of copper.

Oil of tar also makes an excellent wash for timber that is

* Brown's 'Forester,' 4th edit., 1871.

infected with the dry rot, but the smell is very much against its use in situations that are inhabited.

When a mere antiseptic is required, probably one of the best that can be used is carbolic acid in its crude state. The surface of the timber and the place on which it rests should be washed over with it; but, like oil of tar, the smell is objectionable in some situations.

504. To prevent the attacks of the *Sea-worm*, the most effectual remedy is to thoroughly impregnate the wood with creosote. Nails closely driven over the surface of piles below high water, when carefully performed, have been found to protect them from the attack of these animals. This and covering the surface with sheet copper, are perhaps the only methods known of resisting the attack of the *Limnoria terebrans*.

505. The only timber that will resist the *White Ants* is Teak (*Tectona grandis*) and Ironwood (*Sideroxylon*). The Jarrah wood of Australia sometimes escapes their ravages, but all other woods are attacked by them. The only effectual remedy has been creosote; but even that if it has not penetrated the wood thoroughly will not avail.

Corrosive sublimate, chloride of zinc, salts of lead, even creosote and carbolic acid, have all been tried at St. Helena with no more effect than to retard the destruction of the wood for a few months.

For the true ant, or *Formica*, arsenic has been used in the West Indies; and Thunberg has found cajeput oil effectual in destroying the red ants of Batavia: he used it to preserve his boxes of specimens from them. When ants were placed in a box anointed with this oil, they died in a few minutes.*

* Thunberg's 'Travels,' vol. ii., p. 300.

Classification and Structure of Wood.

506. On examining the transverse section of a tree a number of layers or rings will be seen, as stated in Art. 439, regularly disposed around the pith which is generally near the centre of the section; and radiating from the pith towards the bark will also be seen a number of fine divisions called *medullary rays*, with pores or cells between them, often empty but sometimes filled: in the class of wood to which pine belongs these pores appear to be nearly all filled with resinous matter, and a part of each layer or annual ring consists of a hard compact and dark-coloured substance, the other part being lighter-coloured and softer.

Besides the fine divisions or rays referred to, there are in some descriptions of wood other divisions very large and distinct, which radiate in the same way, but are generally of a light silvery colour. These form what is called the "silver grain" of the wood, and produce that fine flowered appearance seen in oak when cut through this grain.

In some kinds of wood, while a part of each annual layer is nearly compact, the remainder of it presents the appearance of a circle of empty pores, of which we have an example in the ash, and which shows remarkably distinct in the section of the Arbutus given by Hill.*

In other kinds of wood the annual layers seem to be nearly uniform in texture, and the line of separation between them is not very distinct. Mahogany is an example of this structure, and the Robinia Caragna of Hill is another of the same kind.

507. The classification of timber given in the following Table is based on the foregoing distinctions.†

* 'Construction of Timber,' p. 136.

† The Table is a modification, suggested by Professor Rankine, of that given in a former edition of this work.

CLASS I.—Pine Wood (Natural order *coniferæ*).

Annual rings very distinct, pores filled with resinous matter, one part of the ring hard, and dark-coloured; the other soft and light-coloured.	Pine, Fir, Larch, Cedar, Cowrie, &c., &c.

CLASS II.—Leaf Wood (Non-coniferous).

Div. I.	With distinct large medullary rays.	*Sub-div. I.*—Annual rings distinct; one side porous, the other compact.	Oak.
		Sub-div. II.—Annual rings not distinct; texture nearly uniform.	Beech, Alder, Plane, Sycamore, &c., &c.
Div. II.	No distinct large medullary rays.	*Sub-div. I.*—Annual rings distinct; one side porous, the other compact.	Chestnut, Ash, Elm, False Acacia.
		Sub-div. II.—Annual rings not distinct; texture nearly uniform.	Mahogany, Walnut, Poplar, Teak, Greenheart, &c., &c.

The only other properties of wood that seem to require explanation are the cohesive force, modulus of elasticity, stiffness, hardness, and toughness.

508. The *cohesive force* of a bar or beam is equal to the power or weight that would pull it asunder in the direction of its length. The weight that would pull asunder a bar of an inch square of different kinds of wood has been ascertained by experiments, which have been made by Muschenbroek,* Emerson,† Rondelet,‡ Anderson, Barlow,§ Hodgkinson,‖ and others. Of these experiments the highest and lowest result have been taken for each kind of wood.

509. The *modulus of elasticity* or weight in lbs. required

* 'Intro. ad Phil. Nat.' † 'Mechanics,' 4to edit., sect. viii.
‡ 'L'Art de Bâtir.' § 'Essay on the Strength of Timber,' &c.
‖ 'Phil. Trans.,' 1840.

to extend a bar of 1 inch square to double its original length (Art. 79) is usually taken as the standard by which the elastic force of one substance is compared with another. Dr. Thomas Young has by means of it given some very elegant demonstrations of the laws of resistance,* and its use must be evident when it is considered that it is only the elastic force of timber that is employed in resisting the usual strains in carpentry. The constant numbers in the rules for the stiffness of timber have the modulus of elasticity for one of their elements.

By means of the modulus of elasticity the comparative *stiffness* of bodies can be ascertained. For instance, its weight for cast iron is 17,000,000 lbs., and its weight for oak is 1,714,500 lbs. Hence it appears that the modulus for cast iron is nearly ten times that of oak, and therefore a piece of cast iron is ten times as stiff as a piece of oak of the same dimensions and bearings.

510. A *hard* body is that which yields but little to any stroke or impressive force; and it may be shown, by the principles of mechanics, that in uniform bodies the degree of yielding is always proportional to the weight of the modulus of elasticity; therefore a table containing the weights of the modulus of elasticity of such bodies shows also their relative hardness and stiffness.

The relative hardness may be determined by means of the modulus of elasticity; but the methods used for ascertaining the hardness of mineral bodies is very defective; and the method proposed by Dr. O. Gregory,† from the theory of percussion, is not susceptible of any tolerable degree of accuracy, from the difficulty of making correct experiments.

As the hardness follows the same laws as the stiffness, cast iron is ten times as hard as oak. But it is necessary to

* 'Lectures on Natural Philosophy.'

† 'Treatise on Mechanics,' vol. i., art. 348.

inform the reader, that when the substance is not uniform, the hardness thus found is that of the hardest part. Thus, in fir it is the darker part of the annual ring that is the hardest, and which determines the extent to which a beam will bend without fracture. Dry wood is harder than green, consequently it is more difficult to work. The labour of sawing dry oak is to that of sawing green as 4 is to 3,* nearly.

511. In respect to the *toughness* of woods, that wood is the toughest which combines the greatest degree of strength and flexibility; hence that wood which bears the greatest load and bends the most at the time of fracture is the toughest. The comparative toughness has been ascertained from the data obtained in the course of the author's experiments, except in a few instances, where he had not specimens sufficiently long for the purpose. In such cases they have been calculated from Barlow's experiments.

512. The opposite to hardness is softness, the opposite to toughness is brittleness, and the opposite to stiffness is flexibility; therefore, when the hardness, toughness, or stiffness of wood is expressed by a low number, it may be considered to have the opposite quality.

513. Oak has been made the standard of comparison both for strength, toughness, and stiffness, and is taken = 100; the mean strength of oak being taken at 11,880 lbs. per square inch, and its modulus of elasticity at 1,714,500 lbs. for a square inch.

Having thus laid before the reader the means adopted for arriving at the properties of timber, it is scarcely necessary to say, that it is those properties which determine its fitness for the different purposes of carpentry. In some cases stiff woods are required, as in the joists and rafters of a building; in other cases tough woods should be employed, as for the

* Belidor, 'Architecture Hydraulique,' tom. i., p. 342.

shafts of carriages; and in other cases strength is necessary, as in ties, and other timbers strained in the direction of their length.

Tough woods, which are also hard, are the most difficult to work, especially if cross-grained; on the contrary, brittle woods work easily; and hard woods preserve the best surface.

In general, where straightness is desirable, stiff woods should be preferred; where sudden shocks are to be sustained, tough woods are the best; where little strength is required, but much labour is to be put upon it, a brittle wood is the most economical; and where a fine surface is to be preserved, a hard wood should be chosen.

NATIVE AND FOREIGN TIMBER USED IN ENGLAND.

Class I.

514. This class comprises all the cone-bearing trees, the annual rings of which are very distinct, and the pores filled with resin or turpentine. It includes some of the most durable and useful kinds of wood.

The pines (*Pinus*) and firs (*Abies*) were formerly included in the same genus, but modern botanists keep them separate. The leaves of the pine are needle-shaped and always green; they grow in groups of two, three, four, and five, surrounded by a membraneous sheath at their base, whereas those of the fir rise singly from around the stem similar to the teeth of a comb. The fir-tree is also distinguished from the pine by its growing in a more pyramidal form, and by the character of its fruit.

Northern Pine.

Pinus sylvestris.)

515. This timber, which has sometimes been called RED FIR, YELLOW FIR,* and SCOTCH FIR, is one of the most durable of the pines. It grows in Norway, Sweden, Russia, and in other parts of Northern Europe. It is also a native of the highlands of Scotland, where the tree often attains a considerable size.

The great forests of Norway, Sweden, and Russia consist almost entirely of this timber and the spruce fir (*Abies excelsa*). It is exported in logs and deals from the ports of these countries as well as from the Prussian ports of Memel, Königsburg, Dantzic, and Stettin in the Baltic Sea. Some of the largest logs come from Stettin, being from 18 to 20 inches square. Those from Dantzic vary in size from 14 to 16 inches square, but can be had in lengths of from 40 to 60 feet, though of late years such long lengths have become scarce in the market. Occasionally timber has been supplied from Dantzic as much as 21 inches square.

The timber exported from Memel is, as a rule, of smaller section and shorter length than that from the other Prussian ports, being seldom more than 13 inches square or 35 feet in length.

The Russian port of Riga exports timber about 12 inches square and 40 feet long, but masts and spars for ships have been obtained 18 to 25 inches in diameter and 70 or 80 feet in length.

The Swedish and Norwegian timber is generally of smaller scantling than that obtained from either Russia or Prussia, being seldom over 12 inches square.

* This term, as well as "Memel fir," "Riga fir," "Dantzic fir," &c., has been used in most of the Tables and by the several authors quoted throughout this work to denote the *Pinus sylvestris*.

The Northern pine is also imported into this country in the form of planks, deals, and battens; the first being usually about 11 inches wide, the second about 9 inches wide, and the last 7 inches wide and of any length above 6 feet; the usual thickness being from $2\frac{1}{2}$ to $3\frac{1}{4}$ inches. The term "deal" is also used to distinguish wood in the state ready for the joiner from "timber," which is wood prepared for the use of the carpenter.

The yellow deals from Christiana are considered the best, being the most durable and mellow, but are wasteful, owing to the quantity of sap they contain. Those from Stockholm and Geflo are next in quality, but are more disposed to warp than the Christiana deals. They are considered very suitable for floors and other work where warping can be prevented. Gottenburg deals, though strong and durable, are considered bad by the joiner.

Archangel and Onega produce excellent deals for joiners' work, though not near so durable in damp situations as those obtained from Christiana. Deals from Wyborg are considered the best Russian deals in the market, but are a little inclined to sap. The knots in the Russian deals are apt to be surrounded by dead bark. The yellow deals exported from Petersburgh and Narva are inferior to those from Archangel or Onega.

Swedish deals, from their liability to warp, cannot, as a rule, be depended upon for joiners' work.

Very durable timber for the carpenter's purpose is exported from Memel and Dantzic. That from the former port is, however, much cleaner than from the latter, which is often full of large knots in a state of decay, and the heart of the timber is sometimes "cuppy," *i. e.* separated from the outside rings, which is supposed to be caused by lightning or severe frosts.

The Scotch variety of the *Pinus sylvestris* is often grown

in England, chiefly for ornamental purposes; but the wood is seldom of much value to the carpenter. It succeeds best in a dry gravelly soil.

In Scotland trees of natural grown wood are sometimes to be seen as much as 3 feet in diameter and 90 feet in height, the timber of which, though of good quality, is not equal to the best foreign kinds.

Tar, pitch, and turpentine are obtained from the Northern or Scotch pine, and the tree is thought not to be injured by extracting them after it has attained a certain age; indeed, it is supposed by some that the wood is improved by being tapped.

It was the opinion of Brindley, the celebrated engineer, founded on observation, "that red Riga deal or pine-wood would endure as long as oak in all situations."* Similar opinions have been held by Semple.†

An instance of the durability of pine is given by Duhamel, who states that the piles of the foundations of an old church, which had existed many centuries, were found to be perfectly sound in the centre, and had retained the colour and odour of resin; but the outside was a little decayed. And Dr. Smith gives an instance of the durableness of natural grown Scotch pine, some of which he had seen after it had been 300 years in the roof of an old castle as fresh and full of sap as newly-imported timber from Memel; "and part of it," he tells us, "was actually wrought up into new furniture."‡

It may be observed here that foreign timber has an advantage that is too seldom allowed to home-grown timber, in its being always more or less seasoned before arriving in this country.

The lightness and stiffness of pine render it superior to any other material for beams, girders, joists, rafters, and

* Darwin's 'Phytologia,' p. 521.
† 'Treatise on Building in Water,' p. 86.
‡ Pontey's 'Forest Pruner,' p. 71.

framing generally. It is also much used for the masts and other parts of vessels. For joiners' work it is more easily wrought, stands better, is nearly if not quite as durable as oak, and is much cheaper.

The colour of the wood of the different varieties of Northern pine differs considerably, the general characteristic being a reddish yellow, or a honey yellow, of various degrees of brightness. A cross section shows alternate hard and soft circles; one part of each annual ring being soft and light-coloured, and the other harder and dark-coloured; the larger medullary rays or silver grain is absent. It has a strong odour and taste of resin, and when the resin is not too abundant it works easily under the saw and plane. The foreign wood shrinks about *one-thirtieth* part of its width in seasoning from the log.

To become familiar with different kinds and qualities of timber requires considerable practice and close observation. Pine should have a fine close grain, the annual rings should seldom exceed one-tenth of an inch in thickness, and be firmly connected together. The nearer the concentric layers are to circles and ellipses, the less likely is the timber to be defective, as sudden swells are frequently caused by "rind-galls," which are wounds in a layer of the wood that has been covered over by the growth of subsequent layers.

Superior pine timber is also strongly charged with resin, which not only gives it strength and elasticity, but also preserves it from insects and prevents fermentation and decay. The colour of good timber should be of a clear or bright yellow, with a reddish cast alternately. The wood should appear hard and dry to the touch. The smell should be strongly resinous, especially when the timber is exposed to the sun or heat, or when the shavings are rubbed between the fingers. It should neither leave a woolly surface after the saw, nor fill its teeth with resin. On the contrary,

when the layers are separate, porous, or open, with tints of a pale red near the heart, and white spots intermixed, or of a dark red, with the resinous particles of a blackish colour, the timber is in a state of decay. Likewise, when pine is cut transversely, and the colour does not appear uniform, but interspersed with veins, and the smell is either entirely gone or has become fetid, the timber may be considered past its prime and approaching a state of decay. Mr. Fincham says, "The experienced mast-maker forms his opinion of the quality of a stick not only from the colour, smell, and appearance of the grain, but by its working; for as a stick is more or less frough or fragile, the greater or less difficulty he has in separating its parts as he chops them off. If the timber is good, its parts, on being separated, appear stringy, and oppose a strong adhesion; and the shavings from the plane will bear to be twisted two or three times round the fingers; whereas, if the stick is of a bad quality, or in a state of decay, and has lost its resinous substances, the chips and shavings come off short and brittle, and with much greater ease."

The inferior kinds of timber have thick annual rings; in some the dark parts of the rings are of a honey yellow; the wood is heavy and filled with soft resinous matter; it feels clammy and chokes the saw. Timber of this kind is not durable, nor fit to resist heavy loads or strains.

The timber grown in Mar Forest is often of this latter kind. In other specimens of inferior timber the wood is spongy, contains but little resinous matter, and presents a woolly surface after the saw. Swedish timber is often of this kind, and is then inferior in strength and stiffness.

The mean strength, stiffness, and toughness of oak being each represented by 100, those of the different varieties of Northern pine will be represented by the following numbers:—

	lbs.		lbs.
The cohesive force of a square inch of foreign timber varies from	7000	to	14,000
Ditto of Mar Forest	7000	„	10,000
Ditto of English growth	5000	„	7000

	lbs.		lbs.
The weight of a cubic foot of foreign pine seasoned varies from	29	„	40
Ditto of English growth	28	„	33
Ditto of Mar Forest	31		

	lbs.
The mean weight of the modulus of elasticity for a square inch of the foreign varieties of the Scotch "fir" of good quality is	1,687,000
Ditto of Mar Forest	845,000
Ditto of English	951,000

Strength of foreign timber,	80;	Mar Forest,	61;	English grown,	60
Stiffness	„	114	„	49	„	55
Toughness	„	56	„	76	„	65

The author was favoured by Mr. John White with a specimen of Norway pine much superior to any of the pine species that had been experimented upon; its strength being to that of oak as 120 to 100, and its weight per cubic foot 39 lbs.

The wood of the *Pinus sylvestris* from cold climates appears to be always much harder than that grown in warmer countries. It is from the under-side of crooked pine-trees that the Laplanders procure what they term "kior," which is as hard as boxwood, and which they use for the bottom of their sledges and for the outer part of their bows. The Norway timber is also harder than that from Riga or other warmer latitudes.

Red Pine.

(*Pinus rubra.*)

516. This timber, which is sometimes called by botanists *Pinus resinosa*, is grown on dry gravelly, sandy, or rocky soils in the northern parts of North America, where the tree

attains a height of 60 or 70 feet, and a diameter of 15 to 25 inches at 5 feet from the ground.

In Canada it is called "Norway pine" and in Nova Scotia "yellow pine," and also "red pine," chiefly from the colour of its bark. The tree is never found growing to a large extent in any particular part of its native forests, but only in comparatively small patches here and there—not covering many acres in extent in any one place.

The wood is of a fine grain and close texture, with a slightly red tinge, and is highly esteemed in Canada and the United States for its strength and durability. It makes beautiful clean timber. Mr. Brown states that he has often seen it cut up at saw-mills on the Ottawa into planking upwards of 35 feet long, without a single knot being exposed to view.*

The timber when cut up is very similar in appearance to the Northern pine exported from Memel, and from which it is often difficult to be distinguished. The knots in the Memel timber, however, are usually smaller and cleaner than in red pine.

The Canadian red pine has been employed to a considerable extent for various purposes in this country. Though excellent timber, it is considered somewhat inferior in strength and durability to the best Baltic pine; but it is often preferred by the shipwright for planks and spars on account of its being soft, pliant, and easily worked. It has, however, usually a greater number of layers of sap-wood than the Baltic pine. The *Pinus rubra* is seldom to be seen growing in this country. The weight of a cubic foot when dry is about 37 lbs.

* 'Forester,' 4th edit., 1871.

White Pine (Weymouth Pine).

(Pinus strobus.)

517. This timber, like the preceding, is a native of Canada and the northern districts of the United States. It is said to have been first introduced into this country by the Earl of Weymouth, hence the name "Weymouth pine." It obtained the name "white pine" from the perfect whiteness of the wood when freshly exposed. The tree grows in almost all varieties of soil between the parallels of latitude 43° and 47°; but attains its greatest dimensions in the upper part of New Hampshire, the State of Vermont, and near the source of the river St. Lawrence. Mr. Brown measured many of the trees as they lay felled on the ground, and taking a number of them, he found the stems to average 150 feet long by 2 feet 9 inches diameter at 5 feet up from the bottom, and some he found that measured 210 feet long, with stems from 5 to 10 feet in diameter, at 4 feet up from the bottom; and on counting the annual layers on the stumps he found them to range between 350 and 425, which may be taken as representing the years of their age.

The timber is exported in logs often more than 2 feet square and 30 feet in length.

The Weymouth pine is one of the largest and most useful of the American pines, and makes excellent masts. The wood is light, soft, and free from knots, easily wrought, and very durable in the comparatively dry climate of America when exposed to air and sun.

The wood is much used by the joiner for mouldings and other work where a clean straight-grained wood is desirable; but it is not so durable in this country as the Baltic pine, nor is it fit for large timbers, being very liable to the dry rot, and it swells in damp weather. It holds glue very well, but is bad for retaining nails.

White pine is in great demand as a good building material in the eastern and northern states of America, being almost the only kind in use for the framework and joinery of houses, and in the form called *clapboards* and *shingles* to cover the roofs. These wooden houses are said to last about twelve or fifteen years. It is also extensively used in the construction of the timber bridges so common in America. The bridge over the Delaware at Trenton (Art. 335), and the celebrated bridges over the Schuylkill (Art. 338) were formed of this timber

	lbs.			
Weight of a cubic foot	28¾	Stiffness ..	95	Oak being = 100.
Cohesive force of a square inch	11,835	Strength ..	99	
Modulus of elasticity	16,335,500	Toughness ..	103	

Yellow Pine.

(*Pinus variabilis.*)

518. Yellow pine is a native of the pine forests from New England to Georgia. The wood is much used in America for many purposes of the carpenter. Mr. Fincham considered it of great value for the masts and yards of the larger classes of ships.* The timber is imported into England chiefly from Quebec.

Another species of yellow pine (*Pinus mitis*), thought by

* 'Outline of Ship-building.'

some to be the same as the
York pine is found in great abundance in the
and throughout the whole of North America, where it is much used for framework, &c. The heart-wood of this species is fine-grained, moderately resinous, strong, and durable; but the sap-wood is very inferior, decaying rapidly on exposure to the weather; it is more durable and of greater strength than the white pine, but does not attain so large a size. The tree grows to a height of 50 or 60 feet, the diameter being about 18 inches.

In the southern states of America the *Pinus mitis* is known as "spruce pine" and "short-leaved pine," to distinguish it from the long-leaved or southern pine (*Pinus Australis*), which is seldom met with higher north than Norfolk, Virginia. The southern pine, which is called Georgia pine in England and the West Indies, is also called yellow pine and sometimes pitch pine in the northern parts of the United States.

PITCH PINE.

(*Pinus resinosa.*)

519. This tree, which is the *Pinus rigida* of botanists, is a native of Canada, and is common throughout the United States of North America; but is most abundant along the Atlantic coast. It is remarkable for the abundance and fragrance of its resin. The wood is heavy, and when of good quality, close-grained, elastic, and durable; but when old or very dry it becomes brittle. The annual rings are far asunder, and the outer rings often contain a large quantity of sap. The colour is redder than the Scotch pine (*Pinus sylvestris*). The wood feels sticky, and is difficult to plane.

The long-leaved Florida pine yields the best quality of wood; but the timber that is sent from the northern parts of Virginia is not so good, in consequence, it is supposed, of

Cluster Pine.

(*Pinus pinaster.*)

520. The Cluster pine, or Pinaster as it is also called, is a native of the rocky mountainous parts of Europe, where it grows to a height of 50 to 60 feet, and sometimes 70 feet; it is also cultivated in British plantations. The tree is *larger than* the Scotch pine, and the wood is soft and not of so red a colour; it produces both pitch and turpentine. Wiebeking says that the wood of the pinaster is more durable in water than in air, it is of a finer grain than either the pine or silver fir (*Abies picea*). Mathew describes it as a valuable kind of red-wood pine, with strong resinous timber, and from not having one-half of the number of sap-wood layers of the common Scotch pine, he should consider it deserving attention as a naval timber; but perhaps the small number of sap-layers is from want of climate: owing to the branches being larger and, in proportion to their size, being joined to the

The timber is employed in the Marine Arsenal, at Toulon, for the outer cases of all packages which are put on board vessels, and also for the piles and props which are used for sustaining the frames of vessels while they are being constructed. In Bordeaux and Provence it is employed for the common kinds of carpentry, for packing-cases, and for fuel.

The weight of a cubic foot of the pinaster is 25½ lbs.

White Fir or Norway Spruce.

(Abies excelsa.)

521. The Norway spruce (*A. e. communis*), which is better known in this country as White Deal, is a native of the mountainous districts in various parts of Europe and the north of Asia. It is the tallest and straightest of our European firs, usually growing to a height of 80 or 100 feet, but the trunk is seldom so thick in proportion to the height as in other species; trees of from 2 to 3 feet in diameter at the lower end are however often to be met with. The forests of Norway produce the tree abundantly.

The spruce fir is largely imported into this country in the

* 'On Naval Timber,' p. 70.

† Loudon, 'Ency. of Trees and Plants,' p. 964.

White deals are also imported from Friedrichstadt, Drontheim, and other ports in Norway, and from Gottenburg, Riga, and other places in the Baltic. At Christiana, Mr. Coxe states, "that each saw-mill is restricted from cutting more than a certain quantity of deals; at that port there are 136 saw-mills, and the quantity permitted to be cut amounts to twenty million standard deals."

White deal unites well with glue and is very durable in a dry state, but is inferior to the Northern pine, and being often knotty is not proportionally strong for horizontal bearings. The deals are much in demand for internal joiners' work, lining furniture which is to be covered with veneers of more expensive wood, and packing-cases.

The wood being fine-grained takes a high polish and does well for gilding on. Christiana white deals and battens are considered the best for panelling and for the upper floors of houses; they are both light and mellow; those from Friedrichstadt have small black knots. The lowland Norway white deals warp and split in drying; both good and bad qualities are sent from Dram. Gottenburg white deals are stringy and are mostly used for packing-cases. Narva in Russia supplies those next best to Norway, and Riga follows third in quality. The Petersburgh white deals shrink and swell with the weather even after being painted.

One of the principal uses to which the spruce fir is applied is for scaffold poles, ladders, spars, and masts to small vessels, for which purposes the greater proportion of the timber imported from Norway is in the form of entire trunks, often with the bark on, from 30 to 60 feet in length, and not more than 6 or 8 inches in diameter at the thickest end.

The wood of the spruce fir is light, elastic, and varying in durability according to the soil on which it is grown; it is much less resinous than the wood of the *P. sylvestris.* According to Hartig it weighs 64 lbs. 11 oz. per cubic foot when green, 49 lbs. 5 oz. when half dry, and 35 lbs. 2 oz. when quite dry. According to the author's observations, white deals shrink about *one-seventieth* part, on becoming *perfectly dry,* from the state they are usually purchased at the timber yards, and what are called dry deals will shrink about *one-ninetieth* part.

It is from the Norway spruce that the Burgundy pitch of commerce is obtained. The tree thrives well in some parts of Britain, and produces good timber, but little inferior to the foreign; it is somewhat softer and the knots are harder, which renders it difficult to work.

A cubic foot of Christiana deal weighs from 28 lbs. to 32 lbs. when dry.
„ Norway spruce (British grown) .. 34 lbs. „

The cohesive force of a square inch of Christiana deal is from..	8000 lbs. to 12,000 lbs.
Ditto of Norway spruce (British grown) .. .	8,000 lbs.

Representing the strength, stiffness, and toughness of oak each by 100,

	Christiana Deal.	British grown Norway Spruce.
The strength will be	104	70
Stiffness..	104	81
Toughness	104	60

American White Spruce Fir.

(Abies alba.)

522. The white spruce fir, named from the colour of its bark, and called in Canada *Epinette*, or rather *Sapinette blanche*, is a native of high mountainous tracts in the colder parts of North America, where it attains a height of 40 to 50 feet. The wood is not so resinous as that of the Norway spruce, but it is tougher, less heavy, not so durable, and generally more liable to twist in drying. It is occasionally imported in deals and planks.

The weight of a cubic foot is	29 lbs. when dry.
The cohesive force of a square inch is from ..	8000 to 10,000 lbs.

Strength	86	oak being 100.
Stiffness	72	
Toughness	102	

American Black Spruce Fir.

(Abies nigra.)

523. The black spruce fir, also named from the colour of its bark, is a native of the northern states of America and Canada, and is very abundant on cold-bottomed lands in the province of Lower Canada, where it forms large forests inter-

mixed with the Hemlock spruce (*Abies Canadensis*). It often attains a height of 60 or 70 feet, and on favourable soil as much as 100 feet, but the diameter of the stems of even the tallest trees seldom exceeds 24 inches.

The colour of the wood is the same as the white spruce, but the black is said to produce much the best timber. It is used in America, where it is valued for its strength, lightness, and elasticity, as knees for ship-building, when neither oak nor larch can be easily obtained.

Red Spruce Fir.

(*Abies rubra.*)

524. This wood, which is also called "Newfoundland Red Pine," is from a large tree which grows in Nova Scotia and about Hudson's Bay, where it attains a height of 70 to 80 feet. The timber of the red spruce is universally preferred throughout the United States for the yards of ships; and for that purpose it is also imported into this country from Nova Scotia.

Michaux says that the red spruce is in no way inferior to the black spruce in the quality of its timber, and it "unites in the highest degree all the good qualities that characterize the species." He also states that instead of being a low tree it is superior in size to the black spruce, as it generally grows in richer soil, and that the wood is reddish instead of being white. In Lawson's 'Manual' it is stated that the red spruce differs essentially both from the white and black species in all its parts, and particularly in its leaves, which are more slender and sharper pointed than either of the others.

The Silver Fir.

(Picea pectinata.)

525. The silver fir differs from the pines and firs previously described in having its cones erect, which has induced botanists to class it as another genus (*Picea*), but in other respects the general character is the same.

The tree is a native of Europe, Asia, North America, and it also grows in British plantations. It is generally to be found in regions more temperate than those in which the spruce firs abound.

The silver fir tree is remarkable for the regularity and symmetry of its pyramidal head, and is readily distinguished from the genus *Abies* by the leaves being more decidedly in two rows, by the cones being upright and having the scales deciduous, *i. e.* falling off annually.

The tree is large, sometimes attaining a height of more than 100 feet, with stems from 3 to 5 feet in diameter. It produces the Strasburg turpentine of commerce. It is supposed to attain its greatest perfection in this country in about eighty years, and the average increase during that period has often been a cubic foot of wood for each year.

The girth of a tree at Woodhouselee, Midlothian, was 7·4 feet in 1759, at 4 feet from the ground, and in 1793 it girted 11·12 feet.

The wood is of a good quality, and much used on the Continent both for carpentry and ship-building. The harder fibres are of a yellow colour, compact and resinous; the softer nearly white. Like the fir it is light and stiff, and does not bend much under a considerable load; consequently floors constructed of it remain permanently level. It is liable to the attack of the worm. Wiebeking says it lasts longer in

the air than in water, and it is therefore more fit for the upper parts of bridges than for piles and piers. The weight of a cubic foot is about 25½ lbs.

Larch.

(Genus *Larix.*)

526. Of the larch-tree there are three species: one European and two American. The European larch (*Larix Europæa*) is a native of the Alps of Switzerland, Italy, Germany, and Siberia, but does not grow on the Pyrenees nor in Spain. The variety from the Italian Alps is the most esteemed, and has been planted to a considerable extent in this country. The larch is a straight and lofty tree of rapid growth, frequently attaining a height of 100 feet. In 1817 a tree of seventy-nine years' growth was cut at Blair Athole, which contained 252 cubic feet of timber; and one of eighty years' growth, at Dunkeld, measured 300 cubic feet; * and a tree of fifty-four years' growth, in Derbyshire, contained 83¼ cubic feet.†

According to Hassenfratz the mean size of the trunk is 45 feet in length, and 33 inches in diameter.

It is extremely durable in all situations, failing only where any other kind would fail; for this valuable property it has been celebrated from the time of Vitruvius, who regrets that it could not be easily transported to Rome, where such a wood would have been so valuable. It appears, however, that this was sometimes done; for we are told that Tiberius caused the Naumachiarian Bridge, constructed by Augustus, and afterwards burnt, to be rebuilt of larch planks procured from Rhætia. Among these was a trunk, 120 feet in length, which

* 'Phil. Mag.,' vol. liii.

† Farey's 'Derbyshire Reporter,' vol. ii., p. 252.

excited the admiration of all Rome.* The celebrated Scamozzi also extols the larch for every purpose of building; and it has not been found less valuable when grown in proper soils and situations in Britain.

In posts, sleepers, and situations where it is alternately exposed to wet and dry, it is found to be very durable. The Duke of Athole has known it to last from twenty to thirty-four years in such situations, particularly the knotty top-wood.

In countries where larch abounds it is often used to cover buildings, which when first done are the natural colour of the wood, but in two or three years they become covered with resin, and as black as charcoal; the resin forms a kind of impenetrable varnish, which effectually resists the weather.

Larch is not so buoyant, however, nor so elastic as Northern pine, and as it does not dry so completely as pine, boards of it are more apt to warp. It is, however, much more tough and compact, and what are very valuable properties, it approaches nearly to being proof not only against water but against fire, as it does not inflame readily: before a larch beam would be completely charred on the surface, a beam of pine or dry oak will be in a blaze beyond the ordinary means of extinguishment.

Wiebeking says it is preferable to pine, pinaster, or fir, for the construction of the arches of wooden bridges; and Mr. Coxe states, that the borderers on the Lake of Geneva prefer it for building their vessels: indeed the larch is useful for every purpose of building, whether external or internal; it makes excellent ship-timber, masts, boats, posts, rails, and furniture. In some parts of Kamtschatka it arrives at a considerable size, and is there used for ships, and lasts extremely well.† It is peculiarly adapted for flooring-boards in situations where there is much wear, and for staircases; in the latter,

* Beckmann's 'Hist. of Inventions,' vol. ii., p. 299.

† Langsdorff's 'Travels,' vol. ii., p. 267.

its fine colour when rubbed with oil is much preferable to that of the black oaken staircases to be seen in some old mansions. It is well adapted for doors, shutters, and the like; and from the beautiful colour of its wood when varnished, painting is not necessary.

The chief objections to the wood of the larch are its liability to warp and twist; but this is said to be obviated by barking the trees in spring while growing, and not cutting them down until the following autumn, as suggested by Chapman, or even for a year afterwards. This is also said to prevent the timber from being attacked by the dry rot.

The wood of the European larch is generally of a honey-yellow colour, and the hard part of the annual rings of a redder cast; sometimes it is brownish white. In common with the pine species, each annual ring consists of a hard and soft part. It generally has a silky lustre, the colour is browner than that of the Scotch pine, and the wood is much tougher. It is more difficult to work than Riga or Memel timber; but the surface is better when once it is obtained. It bears driving bolts and nails better than any other kind of resinous wood, and stands well when perfectly dry.

Two distinct varieties of the European larch are found in this country, one being of a redder colour, harder, of a straighter grain, and more free from knots than the other, which is of a white colour and coarse grain. The white kind is the most common. These varieties are supposed to be caused by some accidental circumstances of soil, site, or impregnation. The author has made experiments on both kinds from the Duke of Athole's woods in Scotland.

In order to try the value of larch as a ship-timber, two ships were built in November, 1820, one of larch from the Duke of Athole's estate, called the 'Athole'; another of Baltic pine, called the 'Nieman.' These vessels, which were both employed on the same kind of service, were examined in

December, 1827, and it was found that the 'Athole' only required a very slight repair, whereas the 'Nieman' was found so very defective that it was proposed to break her up.

The cohesive force of a square inch of larch is from 6000 to 13,000 lbs.

The modulus of elasticity for a square inch is 1,363,500 lbs., and the weight of a cubic foot varies from 29 to 40 lbs. when dry.

Strength of larch	103	oak being = 100.
Stiffness	79	
Toughness	134	

The following experiments were made in a Bramah press by Mr. Renton on the resistance to crushing in the direction of the fibres, of larch of average quality, from specimens sent to the author of this work by the Duke of Athole.

Length in inches.	Scantling in inches.	Weight in lbs. which crushed the piece.	Crushing force in lbs. per sq. inch.	Remarks.
6	1·94 × ·94	9,600	5285	This piece bore 7040 lbs. for 2 hours without sensible fracture.
"	,,	10,880	5979	
"	2·00 × 1·00	8,960	4480	
"	,,	9,600	4800	
8	,,	8,960	4480	
9	,,	8,960	4480	
		Mean ..	4917 lbs. per square inch.	

Out of the specimens sent by the Duke of Athole, three were selected of average quality, each being 2 inches in breadth, 1 inch deep, and were placed on supports 3 feet apart. A load of 90 lbs. being placed on the middle of each, the permanent set at the end of fifteen hours was only barely sensible.

The first piece broke with 423 lbs.; the second, with 425 lbs.; and the third, with 355 lbs.

From these trials we find that larch bears a stress of 2450 lbs. per square inch without permanent alteration, and an extension of $\frac{1}{432}$ of its length. The weight of the modulus of elasticity for a square inch is 1,020,000 lbs. And the weight of a cubic foot when dry is 34¼ lbs.

According to Hartig, the wood of the larch weighs 60 lbs. 13 oz. per cubic foot when green, and 36 lbs. per cubic foot when dry.* From experiments made by Mr. Rait, given in Brown's 'Forester,' the sap-wood of green larch weighed 48 lbs. per cubic foot, and when dry 32½ lbs. The heart-wood weighed when green 35 lbs., and when dry 31½ lbs. per cubic foot.

527. AMERICAN BLACK LARCH, OR HACKMATACK (*Larix pendula*).—This wood, which is also called Tamarak, is found in North America, from Newfoundland to Virginia, where it attains a height of nearly 100 feet. Michaux describes the American larch as a tall slender tree, with a trunk 80 or 100 feet high, and only 2 or 3 feet in diameter. Its numerous branches except near the summit are horizontal, or declining. The bark is smooth and shining on the trunk and large branches, but rugged on the smaller branches. The leaves are flexible and shorter than those of the European species. The wood is said to be nearly equal to that of the European larch, "being exceedingly strong and singularly durable."

528. AMERICAN RED LARCH (*Larix microcarpa*) is also a native of North America; its growth is comparatively diminutive, and hence it is of less value and service than the common larch. Trees of this species in the Duke of Athole's plantations in Scotland have been found at fifty years' growth to contain only about one-third as many cubic feet as the common European larch.

* Nordlinger's 'Technical Properties of Woods.'

Cedar of Lebanon.

(*Cedrus libani.*)

529. The cedar of Lebanon is a cone-bearing tree, and an evergreen; it is a native of Mount Libanus, whence it has its name. The finest cedars in the time of Vitruvius grew in Candia and Africa; and there were also some grown in Syria, but we do not know of what species.

It grows to a considerable size; the mean size of the trunk, according to Hassenfratz, is about 39 inches in diameter and 50 feet in length. Several very fine cedars have been produced in this country. The tree which furnished the specimens on which the author made his experiments was 34 inches in diameter; it was grown at Ditton Park, near Windsor.

The wood is said to be very durable in its native country. It is stated by Pliny that in the Temple of Apollo, at Uttica, cedar was found of nearly 1200 years old. According to Vitruvius, the statue of Diana, in the famous Temple at Ephesus, was of cedar, as well as the timber-work of the floor and ceiling of that edifice; and he further states, that the timber-work of the most celebrated temples of antiquity was in general executed in cedar, on account of its extreme durability. The cedar used for statues was most probably the oxycedrus (see Art. 531); but though Vitruvius describes the cedar as having a leaf like cypress, that used for beams, floors, and other parts of the temples, was most likely to be the *Cedrus libani*, as it does not appear that the other kinds are large enough for such purposes. Cedar of Lebanon was used by Solomon in the construction of the Temple at Jerusalem.

It has no perceptible large medullary rays, but when

planed where it has been cut across the annual rings, the smaller rays present a very minute and beautiful dappled appearance. The general colour of cedar is a rich light-yellowish brown; the annual rings distinct; each ring consisting of two parts, the one part harder, darker coloured, and more compact than the other.

It is a resinous wood, and has a peculiar and powerful odour, with a slightly bitter taste, and is not subject to the worm. It is straight-grained, and easily worked, but readily splits.

The cohesive force of a square inch of cedar is 7400 lbs.; the weight of its modulus of elasticity for a square inch is 486,000 lbs., according to the author's experiments; and the weight of a cubic foot seasoned is from 30·5 to 38 lbs.

Strength of cedar	62	
Stiffness	28	oak being = 100.
Toughness	106	

From these proportions it appears that it exceeds the oak in toughness, but is vastly inferior in stiffness and strength.

Juniper.

(Genus *Juniperus*.)

530. It is the wood of this tree with which we are so familiar under the name of Cedar, though belonging to a different genus. The juniper is common as a shrub in all the northern parts of Europe. On the sides of hills its trunk grows long, but on the tops of rocky mountains and in bogs it is merely a tufted shrub. The wood of the juniper is hard and durable. The bark is so tenacious that it may be formed into ropes, and the berries are used for imparting the peculiar flavour to gin.

531. The species called the Brown-berried Cedar (*Juni-*

perus oxycedrus) is a native of Spain, the south of France, and the Levant. The wood of this species is supposed to have been the famous cedar of the ancients, so much celebrated for its durability, and of which they made their statues before the use of marble was known in that branch of the arts.

532. Virginian Red Cedar (*Juniperus Virginiana*).—This species is found in the United States of America and Canada, on dry, rocky hill-sides, but it is not now plentiful in any particular district of these countries. It is also found in the West India Islands, where it attains a considerable height, though according to Mr. Brown it does not even in its native woods ever attain the size of a large tree, as there he never found it much above 45 or 50 feet high, with a stem of from 12 to 18 inches in diameter, and generally smaller. Indeed in this country, where it was introduced so early as 1664, it appears to thrive as well as it does in its native woods.*

The tree produces excellent timber, and is much sought after in America for wardrobes, drawers, boxes, and various kinds of furniture, being avoided by all insects owing to its bitter taste. It is best known in this country from its being used for covering black-lead pencils.

The wood is light, brittle, and nearly uniform in texture; the colour is a brownish red, but the sap-wood is nearly white; the odour is strong and peculiar, which renders it unfit to be used for internal joiners' work in any considerable quantity. The red cedar is imported into this country in pieces of from 6 to 10 inches square.

The weight of a cubic foot when dry is about $40\frac{1}{2}$ lbs.

533. Bermuda Cedar (*Juniperus Bermudiana*).—This wood grows extensively in Bermuda and the Bahama Islands, of which it is a native. It was formerly much used in ship-

* 'Forester,' 4th edit., 1871.

building, and many of the timbers of the Spanish ships taken in the war with Spain were of this species. The wood much resembles the Virginian cedar, both in colour and grain, but there is a difference in the foliage and branches of the trees; in the latter they both point upward, whereas in the former they are either horizontal or drooping.

The Bermudian cedar is also used for pencils, and for internal joiners' work, as well as for ship-building. The wood is extremely durable, where attention is paid to ventilation, and when freed from the white outside or sap. Instances have been known of its lasting nearly 200 years; and in one case a piece that had been taken quite sound from a house, which had been built nearly 150 years, was worked up as timber for a boat. In salt water, as outside planking for vessels, it may be expected to last about forty years; the objection to it for this purpose being its brittleness and offensive smell when in confined situations. It is used in Bermuda for rafters, bond-timbers, joists, &c.; and when well seasoned, it may be used for doors, window-frames, and sashes. The defect of freshly-hewn timber for this purpose is that it exudes a resinous substance, which defeats all attempts to give it a workmanlike finish. It is not so liable to shrink on seasoning as other kinds of timber, seldom losing more than 1 or 2 lbs. in the cubic foot from the green state. Owing to the great demand for the timber at one time exhausting most of the old timber, it is difficult to procure Bermudian cedar larger than about 8 inches square.

The weight of a cubic foot is about $46\frac{3}{4}$ lbs

According to Fincham's experiments the transverse strength of Bermudian cedar is considerably more than that of American red pine; but from experiments made by others this appears doubtful. It is probably not equal to more than three-fourths as strong as the best red pine timber.

Yew.

(*Taxus baccata.*)

534. The Common Yew is a native of Europe, North America, and Japan. It used to be very plentiful in England and Ireland, and probably also in Scotland. Cæsar mentions it as having been abundant in Gaul. It is now found in most parts of Europe, at elevations ranging from 1000 to 4000 feet, and is frequently met with on the Apennines and the Alps, in Greece, Spain, and the Pyrenees, and also in Great Britain. The tree is of slow growth, and attains a great age, some in this country being well known to be about 1000 years old.* It rises from the ground with a short but straight stem, which at the height of 3 or 4 feet sends out very numerous and spreading branches, forming a dense head, usually when full grown from 30 to 40 feet in height. The diameter of the stem is often very great. Evelyn mentions one at Crowhurst of 30 feet in circumference, and another at Braburne Churchyard, in Kent, of nearly 20 feet in diameter.

The wood of the yew is very hard, close, and fine-grained, flexible, elastic, splitting readily, and of great durability; it is also very durable for fencing, so much so that in some parts of England where it is plentiful there is a common saying that a paling post of yew will outlast a post of iron. Floodgates for ponds or mill-streams made of it are said to be of incredible duration. Before the invention of fire-arms, the yew was used in making the long-bow, and was one of the timbers of which it was directed to be made by a statute passed in the fifth year of the reign of Edward IV.

The colour of the wood is of a fine orange or deep brown; the sap-wood, which is also very hard, is white, but does not

* Brown's 'Forester,' 4th edit., p. 379.

extend to any great depth. The yew is a beautiful wood for cabinet-making, but it requires a long time to dry; it shrinks, however, very little in seasoning. The weight of a specimen in the Exhibition of 1851 was 41·7 lbs. per cubic foot. The cohesive strength, according to Bevan, is 8000 lbs.

Cypress.

(*Cupressus sempervirens.*)

535. This tree, which is the species known as the Upright Cypress, derives its name from the Island of Cyprus, where it grows in great abundance; it is also a native of Asia Minor, Persia, and the south of Europe. It is cultivated in all the countries along the shores of the Mediterranean. It thrives best in a warm sandy or gravelly soil. The tree also grows in England, but is not much cultivated. In its native countries it grows to the heights of 70 to 90 feet, with stems thick in proportion, but in England it seldom attains a greater height than of about 40 feet. The tree is evergreen, and grows with all its branches in an upright direction, closely pressed to the stem.

Of all timber, that of the cypress is supposed to be the most durable. The doors of St. Peter's Church at Rome, which it is asserted had been formed of this material in the time of Constantine, showed no sign of decay when, after the lapse of nearly 600 years, they were taken down by Pope Eugenius IV., and replaced by gates of brass. The Athenians, in order to preserve the remains of their heroes, buried them in coffins of cypress, and the coffins in which the Egyptian mummies were found are usually of the same material. For furniture it is said to be equal to mahogany, for though not so beautiful in its colour, it is stronger, resists the worm equally, and its odour repels insects from whatever may be

contained in a cabinet or chest made of it. In Candia and Malta it is much used for building purposes, and it is there considered the most durable of all timber.

The weight of a cubic foot is about 40½ lbs.

COWRIE.

(Dammara Australis.)

536. The Cowrie, or Kauri, called also the Pitch-tree, is a native of New Zealand, and one of the most magnificent of the Coniferæ. It is said to grow to a height of 80 to 140 feet, with a straight clean stem from 4 to 8 feet in diameter, and contains a considerable quantity of resin, which exudes from it spontaneously. The wood is close, even, and fine-grained; the texture uniform, the colour a light yellowish brown, with a silky lustre, and the annual rings marked by a line of a deeper tint of the same colour. In 1856 two spars of this timber were imported, 100 feet long and 34½ inches in diameter, said to be without a knot.

The cowrie is chiefly used in this country for the masts and spars of ships, for which it appears to be well adapted, as well as for joiners' work, as it is less liable to shrink, and stands equally well with the pines and firs of Europe and America; it also unites well with glue. It is found, however, to buckle and expand very much when cut into narrow strips for inside mouldings. Mr. Fincham exposed to the weather for more than eighteen months a piece of cowrie half an inch thick and about 12 inches wide, with a wind-shock extending part of the way up from one end, at the end of which time "it underwent no other alteration than that the sap that was on it to some distance from one edge disappeared, and the wood was left with the colour and firmness fully elaborated." *

* 'Papers on Naval Architecture,' vol. i., p. 56.

The cohesive force of cowrie is from 9600 to 10,960 lbs. per square inch.

The weight of the modulus of elasticity for a square inch is 1,982,400 lbs., and the weight of a cubic foot when dry varies from 35 to $40\frac{1}{4}$ lbs.

Class II.

537. This class includes all non-coniferous trees; they are distinguished from the coniferous trees by the fruit and shape of the leaves, by containing no turpentine, and by the hardness of the wood. Many of the trees included in this class have been arranged by botanists under different natural orders.

Division I.

Large Medullary Rays, or silver grain distinct.

Sub-div. I.—Annual rings distinct, one side porous, the other compact.

Oak.

(Genus *Quercus.*)

538. Of the Oak there are upwards of sixty distinct species known to botanists, chiefly natives of Europe and America, several of which produce valuable timber. Five kinds of oak are enumerated by Vitruvius, *viz.* the "esculus," the "cerrus," the "quercus," the "suber," and the "robur," the timber of each being distinguished by its peculiar properties;* but it would be difficult to identify some of the kinds mentioned by him with the species described by modern writers on botany.

Vitruvius shows, however, by his observations that the peculiarities of the different kinds were attended to, and they must have also been well understood by the Gothic

* Lib. ii., cap. ix.

builders in this country, for in the roofs and beams of most of their buildings we find a very superior kind of oak which closely resembles and is often mistaken for chestnut (see Art. 560). This kind was sometimes called the "Irish Oak." Evelyn commends the Irish oak "for resisting the worm,"* but to what species of oak he alludes it is difficult to say.

At the present time the oak grown in Sussex is esteemed the best which England affords, though of late years the good "heart of oak" timber, from which it obtained its character, is becoming scarce. According to Marshall the superiority of the Sussex oak is chiefly to be attributed to the nature of the soil,† and perhaps also in some degree to good management, for proper attention and skill in the cultivation of trees make a considerable difference in the value of the timber.

English oak is spoken of in general by practical men as though there were but one species, and no difference in the quality of the wood except that produced by soil and situation; but to botanists two distinct species have long been known,‡ *viz.* the *Quercus pedunculata*,§ and the *Quercus*

* 'Silva,' Hunter's edit., vol. ii., p. 222.

† 'Rural Economy of the Southern Counties,' vol. ii., p. 109.

‡ See Ray's 'Synopsis Methodica Stirpium Britannicarum,' p. 440.

§ This tree, according to Sir J. E. Smith, 'Flora Brit.,' vol. iii., 1026, was called by Linnæus and the older botanists the *Quercus robur*, which he has followed. It also appears to be the *robur* of Vitruvius, for he states that the robur is less liable to warp than the *quercus* (book ii., chap. iii.), which is precisely the case with the two English oaks, as the wood of the "robur" of Smith is much less liable to warp than that of the sessiliflora. Again, the description given by Vitruvius of the wood of the quercus in book ii., chap. ix., agrees in everything with the properties of that of the sessile-fruited oak; and as he describes the wood only, it is by it alone that the species is to be known. Perrault (in his notes on Vitruvius) and Evelyn (in his 'Silva') apply the name robur to the sessile-fruited oak; but had these writers known that the wood of the sessile-fruited oak is more flexible than that of the other kind, they would not have done so.

sessiliflora. Some however have considered these as mere varieties of one species, *viz.* the *Quercus robur.**

539. Common British Oak (*Q. pedunculata*) is a native of nearly all parts of Europe, from Sweden to the Mediterranean. It is said to be found in the north of Africa and a part of Asia. It is that which is most frequently met with in the woods and hedges of the south of England and in the forests of France; but in Germany the *Q. sessiliflora* is more common.†

The leaves of this species are irregularly sinuated, with short or scarcely any footstalks (*petioles*); the acorns have long stalks. In favourable situations this species attains an immense size. A fine healthy tree growing in the grounds of Earl Cowper, at Panshanger, Herts, in 1820, measured nearly 18 feet in circumference, at 5 feet from the ground; and the whole height of the tree exceeded 75 feet. The wood of this species has often a reddish tinge; the larger medullary rays are always very numerous, producing a large flowery appearance. The grain is tolerably straight and fine, and it is generally free from knots, sometimes closely resembling foreign wainscot. It splits freely, and makes good laths for plasterers and slaters; and it is decidedly the best kind of oak for joists, rafters, and any other purpose where a stiff and straight-grained wood is desirable.

540. The Sessile-fruited Oak (*Q. sessiliflora*) is dispersed over the same range of countries as the common British oak, but seems to predominate in the forests of Germany, where it is said to grow to valuable timber on a greater variety of soils than the latter. The *Q. sessiliflora* appears to have been first noticed as a distinct species in this country by Mr. Bobart, in Bagley Wood, and near Newbury, in

* Rhind's 'Hist. of the Vegetable Kingdom.'

† Brown's 'Forester,' 4th edit., p. 177.

Berkshire, and called by him, "Bay Oak."* It has been observed by Miller near Dulwich, in Surrey, and it appears to be the common oak of the neighbourhood of Durham, and perhaps generally of the north of England.

There are also some very fine trees in the Earl of Mansfield's grounds at Kenwood,† where the author had an opportunity of comparing the trees of the two species, but could not observe any difference in their growth or general form, except that the sessile-fruited oak had a more graceful appearance, which renders it superior as an ornamental tree. In Bagot Park, Staffordshire, is a very large one, which goes by the name of the Squitchbank Oak, being upwards of 43 feet in circumference at the base, and 61 feet high. At Hazelgrove, in Somersetshire, is a fine oak 80 feet in height, and 30 feet in circumference at 4 feet from the ground.

The leaves of the sessile-fruited oak have rather long footstalks, often nearly an inch in length, and they are more regularly and less deeply sinuated than those of the common or peduncled oak. The acorns sit close to the branches, having very short or scarcely any stalks. The wood is of a darker and more uniform colour, the grain less varied, the larger medullary rays not so abundant as that of the common oak; it is heavier, harder, and more elastic. The smoothness and gloss of the grain makes it resemble the wood of the chestnut. It is very liable to warp and become shaky in seasoning, also tough and difficult to split, which renders it unsuitable for laths. This is most probably the reason why oak laths are so seldom used in the north of England.

As regards the durability of the two species of oak, Mr.

* Ray's 'Synopsis, &c.,' p. 440. 'Flora Brit.,' vol. iii., 1026–7.

† These trees were first pointed out to the author by his brother, Mr. R. Tredgold, whose assistance in collecting and examining specimens of the leaves, fruit, and wood of these and other trees was very useful.

Fincham relates an experiment made in the year 1832. "The late Navy Board having, in the year 1830, directed a quantity thereof to be supplied to Portsmouth Dockyard, and to be tried 'as thick stuff or plank in the sides of a ship, or as timber in her gun-deck beams.'

"At that time the timber of the *Q. sessiliflora* was supposed to be so deficient of durability that the order of the Navy Board to use these descriptions of oak, 'one kind against the other,' included a special caution 'not to place it in situations where it would be difficult and expensive to remove it, in consequence of the number of fastenings that would go through it.' The timber was, therefore, suitably applied in building the 'VINDICTIVE,' forty pieces of the *Q. robur* (*pedunculata*) were placed on the starboard side, and forty pieces of the *Q. sessiliflora* on the port side.

"At the expiration of seventeen years the course of the experiment was examined. It was then found that in the short stuff placed between the ports the two kinds of oak were equally sound; but in the planking upon the outside of the ship the *Q. sessiliflora* was found in a better state of preservation than the *Q. robur* (*pedunculata*).

"So far as the evidence of the above experiment goes there appears to be no reason to prefer the *Q. robur* to the other species of oak for naval uses." *

Mr. Brown, in his 'Treatise on Forestry,' states, "At one time I considered the timber of the *Q. sessiliflora* inferior to that of *Q. pedunculata*; but from more extended observations on the subject of oak timber within the last ten years, I am now led to state that the timber of the one sort is for all purposes as good as that of the other. In some experiments which I made recently in regard to the comparative strength of the timber of the two kinds, I found that a beam of the *sessiliflora* bore fully a greater strain under a given weight

* 'Outline of Ship-building,' 3rd edit., p. 13.

than one of equal dimensions of the *pedunculata*. Indeed, for all purposes to which oak timber is applied, that of the *sessiliflora* is used as plentifully as that of the *pedunculata*, and in old buildings its durability has been found to be equal to the timber of the other kind." When young the timber of the *sessiliflora* is of a more open texture than that of the *pedunculata* of the same age; but as it becomes older it is found as compact and solid as the latter. This arises from the tree being of a more free growth in its young stages than the other is. It appears, as far as can be determined from the structure of the wood, that the fine oak found in old Gothic roofs is of the sessile-fruited kind. At the same time it must be owned that our means of judging are not so satisfactory as to enable us to decide on this point with certainty; but we know that the old oak is very durable.

The strength, elasticity, toughness, and hardness of the sessile-fruited oak render it superior for ship-building; it is, however, both heavier and more difficult to work than the common oak. The wood for the old 'Sovereign of the Seas' was from the north,* and it is probable that the greater part of it was of the sessile-fruited oak. The hardness of the timber "when taken in pieces after forty-seven years' service" is in favour of this conjecture.

In order to make experiments on the two species, when grown at the same place, and nearly of the same age, the author was supplied by Mr. Atkinson with specimens from trees grown at the Deepdene, near Dorking, Surrey, which were directed by the proprietor, Mr. Hope, to be cut for the express purpose of comparing the woods.

The trees were cut a little before the fall of the leaf, and being sawed into small scantlings, after drying two months they were submitted to experiment.

The following Table shows the results of trials on two of

* 'Encyclopædia Britannica,' art. Dry Rot.

the pieces, each being an inch square, sustained by supports 24 inches apart, and the weight applied in the middle of the length.

Species of Oak.	Specific Gravity.	Weight of a cubic foot in lbs.	Comparative Stiffness or Weight that bent the piece seven-twentieths of an inch.	Comparative Strength or Weight that broke the piece.
			lbs.	lbs.
Q. pedunculata ..	·807	50·47	167	322
Q. sessiliflora ..	·879	54·97	149	350

Both these specimens broke short without splitting, therefore these experiments offer a very fair view of the properties of the two species. The *sessiliflora* bent considerably more at the time of fracture than the *pedunculata*, but it could not be measured with that correctness which is necessary to render such data useful.

The following Table contains the values of the cohesive force, and modulus of elasticity, calculated from the above experiments.

Species of Oak.	Cohesive Force of a square inch in lbs.	Weight of Modulus of Elasticity in lbs. for a square inch.	Comparative Toughness.
Q. pedunculata ..	11,592	1,648,958	81
Q. sessiliflora ..	12,600	1,471,256	108

* These pieces were hastily and therefore imperfectly seasoned; but as they were treated exactly alike this would not affect the comparison.

Similar results in favour of the *sessiliflora* were obtained in experiments made on six pieces which had been cut out of the specimens used in the 'Vindictive,' as follows:—

	Q. pedunculata.	*Q. sessiliflora.*
Average breaking weight	931 lbs.	1032 lbs.
„ deflection at time of breaking ..	$4\frac{1}{4}$ inches.	$5\frac{5}{8}$ inches.
„ specific gravity	·737	·809

Each piece was 2 inches square and 6 feet long between the supports; the load being placed on the middle.

541. There is another kind of oak called the DURMAST Oak, said to be a variety of the *Q. sessiliflora*, which is a native of France and the south of England. The wood is not so strong nor of so firm a texture as the English oak, and the tree retains its foliage to a much later period in the season.

542. A considerable quantity of oak is exported from Norway, also from Riga, Dantzic, Memel, and other ports in the Baltic Sea: to what species it belongs has not been clearly ascertained. It is distinguished from the British oak, to which it is inferior, by the straightness of its grain and freedom from knots. Dantzic oak is much used in planks for the bottoms of ships, for decks and other purposes. The wood is close-grained and compact, though sometimes the grain is rather short. Memel oak is finer in grain than the Dantzic oak. It is clean and well adapted for the best descriptions of millwrights' and shipwrights' work. Oak is also exported from Norway, under the name of "Clapboard," and from Holland under the name of "Dutch Wainscot." The latter is grown in Germany, from whence it is floated down the Rhine for exportation. Wainscot may be easily distinguished from clapboard, to which it is superior, by the absence of the white-coloured streaks, which cross the former in all directions. These are less liable to warp and split when in thin boards than English oak, but are much softer, and in other respects inferior to it.

543. The Austrian oak is another variety of the European species, but of which the author has not been able to de-

termine. The tree is taller than the English oak, and the wood is whiter, softer, and less durable.

544. Of the American species the CHESTNUT-LEAVED OAK (*Q. prinos*) is a tall tree, remarkable for the beauty of its form. The wood of some varieties is coarse-grained, but very serviceable and much used for wheel-carriages in America.

545. The RED OAK (*Q. rubra*) is a native of Canada and the country west of the Allegany Mountains. It is called the red oak from the leaves changing to a red or purple colour before they fall off. It is a large and fine tree of 90 or 100 feet in height, and of rapid growth. The wood is used for staves and other purposes, but is light, spongy, and not very durable.

546. WHITE OAK (*Q. alba*), so called from the whiteness of its bark, is a native of the woods from Canada to Carolina, and grows to an immense size in some of the middle states, often attaining the height of 70 or 80 feet, with a trunk from 5 to 7 feet in diameter.

The timber of the white oak has a whitish-brown colour, with a reddish tinge, is tough and pliable, and is preferred to all other kinds in America for both house and ship carpentry, being the most durable of any. The wood is less durable, however, than the British oak, but is of a quicker growth and of straighter grain.

The white oak is not suitable for boards, as it shrinks about $\frac{1}{32}$ part in seasoning, and is very subject to warp and crack.

It is the timber of this species that is exported from Canada to Europe under the name of "American Oak."

547. The IRON OAK, or post oak (*Q. obtusiloba*) is another American species that produces valuable timber. It is found most abundantly in the forests of Maryland, and Virginia, where it is frequently called "Box White Oak," but is rarely seen farther north than the mouth of the Hudson River.

The tree seldom attains a greater diameter than about 15 inches, and on this account is chiefly used for posts and fencing. The wood has a yellowish hue and close grain, and is said to exceed the white oak in strength and durability. It sometimes attains a height of 50 or 60 feet.

548. The LIVE OAK (*Q. virens*). This is considered the best of the American kinds for ship-building. The tree grows, in the southern states of America, to a height of 40 or 50 feet, with wide-spreading branches, and a trunk of from 12 to 24 inches in diameter. It is rarely found farther north than the neighbourhood of Norfolk, Virginia, nor farther inland than from 15 to 20 miles from the sea-coast; but it is found in abundance along the coast southwards as far as the mouth of the Mississippi. The wood has a yellowish tinge, is heavy, compact, and of fine grain. It is stronger and more durable than any other species, and is considered invaluable for the purpose of ship-building, for which it is exclusively reserved. Mr. Knowles states that out of 507 pieces which had been in the 'ESSEX' frigate for twelve years, only six were found to be defective.

549. According to Hassenfratz, the mean size of the trunk of the

Common oak is	45 feet in length and	32 inches diameter.
White American oak ..	58	,,	35	,,
Red American oak ..	48	,,	32	,,

550. OAK of a good quality is more durable than any other wood that attains a like size. Vitruvius says, it is of eternal duration when driven into the earth; and it is well known to be extremely durable in water; and in a dry state it has been known to last nearly 1000 years. The more compact it is, and the smaller the pores are, the longer it will last; but an open porous and foxy-coloured oak, which grows in some parts of Lincolnshire, is not near so durable. Chapman very

justly observes that the heart of such oak is scarcely superior to the sap of better kinds.

The chief use of oak before the introduction of iron was for ship-building, which consumed enormous quantities. In 1788 more than 50,000 loads of timber were required for the construction and repair of the British Navy.*

It is useful for many purposes besides ship-building, particularly in situations where it is exposed to the weather. It makes the best wall-plates, ties, templets, king posts, and indeed it is best suited for every purpose where its warping in drying and its flexibility do not render it objectionable; but, as Vitruvius has observed, it is very liable to twist and cause cracks in the work in which it is employed.

The colour of the oak is a fine brown, and is familiar to everyone: it is of different shades; that inclined to red is the most inferior kind of wood. The larger medullary rays are in general very distinct, producing beautiful flowers when cut obliquely. Where the rays are small and not very distinct the wood is much the strongest. The texture is alternately compact and porous, the compact part of the annual ring being of the darkest colour, and in irregular dots, surrounded by open pores, producing beautiful dark veins in some kinds, particularly in pollard oaks.

It has a peculiar smell, and the taste is slightly astringent. It contains gallic acid, and is blackened by contact with iron when it is damp.

The young wood of English oak is very tough, often cross-grained; and difficult to work. Foreign wood and that of old trees are more brittle and workable.

Oak warps and twists much in drying, and shrinks about *one-thirty-second* part of its width in seasoning, according to Mr. Couch's experiments.

The cohesive force of oak varies from 7850 to 17,892 lbs.

* 'Report of Commissioners of Woods and Forests for 1812.'

per square inch. The mean of Barlow's experiments is 10,000 lbs. 11,880 has been taken in this work as a standard to compare with the other woods, being the result of an experiment on a specimen of a mean quality.

The weight of a modulus of elasticity for a square inch is 1,714,500 lbs., from a mean of various specimens.

The weight of a cubic foot of different kinds of oak is as under :—

English oak from ..	45 lbs.	to	58 lbs.,	seasoned.
Riga oak	43	„	54	„
Red American oak ..	37	„	47	„
White „ ..	50	„	56	„
Adriatic oak	58	„	68	„

Representing the strength, stiffness, and toughness of the common English oak (*Q. pedunculata*) each by 100, it may be compared with the other kinds as under :—

	Common English Oak.	Riga Oak.	American Oak.	Dantzic Oak.
Strength ..	100	108	86	107
Stiffness ..	100	93	114	117
Toughness ..	100	125	64	99

It is necessary to observe, that the specimens of Riga and Dantzic oak were of the best quality.

Division I. (*continued*).

551. *Sub-div. II.*—Annual rings not distinct; texture nearly uniform.

Beech.

(*Fagus sylvatica.*)

552. This is the common beech of our country, which is also a native of most of the temperate parts of Europe from Norway to the Mediterranean, and is said to be plentiful in the

southern parts of Russia. It is found in considerable quantities throughout Great Britain, particularly in the southern and midland parts of England where the soil is of a chalky description.* Being a hardy tree it will grow, however, in almost any situation where the soil is good and dry.

In localities favourable to its growth, the beech often attains a large size. In parts of England and Scotland trees are to be found as much as 100 feet high, and 4 to 6 feet diameter, at about 5 feet from the ground. According to Hassenfratz the mean size of the trunk is about 44 feet in length and 27 inches in diameter.

The wood of the beech grown on dry and suitable soils is whiter than that grown in damp valleys; in the latter case it loses its strength in drying and becomes brittle.

Beech soon decays in damp situations, but is more durable when kept in a dry state; in either case it is very liable to be destroyed by worms.

It is very durable, however, when constantly immersed in water. Duhamel observes that water-seasoned beech is much less subject to worms than that seasoned in the ordinary way; and Ellis says, to preserve it from worms, it ought to be cut about a fortnight after Midsummer, and planked immediately; then the planks should be put in water for about ten days and afterwards dried.

Beech is not useful in building, because of its rotting so soon in damp situations, but it is very useful for piles where it will be constantly wet; or for the knees and planking of vessels for which the clear straight stems render it well adapted.

It is used in the manufacture of various tools, for which its uniform texture and hardness render it superior to any other wood. In England a great proportion of common furniture, such as chairs, tables, bedsteads, which are usually either

* Marshall's 'Southern Counties,' vol. ii.

stained to imitate mahogany, or painted in imitation of rosewood and other foreign woods, is made of beech. It is also used for the panels of carriages, and for a variety of other purposes. Before the introduction of iron, beech was much used instead of rails on the tramways to the collieries about Newcastle, and in other parts of the country.

The colour of beech is a whitish brown, of different shades: the darker kind is called brown, and sometimes black beech; the lighter kind is called white beech. The texture is very uniform; the larger medullary rays are finer and do not extend so far in the length of the wood as in oak, therefore the flowered appearance of the grain is smaller.

The annual rings are rendered visible only by being a little darker on one side than the other. It is uniformly porous, and is easily impregnated, as in Boucherie's process (Art. 502), with substances to prevent its decay. The line of separation between the heart and sap-wood is not so distinct as in oak and other timber where the heart-wood is always of a deeper colour than the exterior or sap-wood.

Beech has no sensible taste or smell; it is not very difficult to work, and may be brought to a very smooth surface.

The white kind is the hardest, but the black is tougher; and Evelyn says it is more durable than the white.

Beech is subject to a disease called the "white dote" by workmen, consisting of white spongy veins, which takes place in healthy timber very shortly after the tree has been felled, owing to the alternations of wet and dry: this disease absorbs the moisture of the log, and in time will render the timber quite unserviceable.

The timber possesses a caustic juice, which, according to Mr. Fincham, is very injurious to metallic fastenings, as those in beech plank on the bottoms of ships have been found nearly destroyed.*

* 'Outline of Ship-building.'

The cohesive force of a square inch of beech varies from 6070 to 17,000 lbs.; the weight of its modulus of elasticity is about 1,316,000 lbs.; the weight of a cubic foot dry varies from 43 to 53 lbs. The higher numbers are from Muschenbroek, both in cohesive force and weight, and they are certainly much above any observed by the author, or those of any other writer: about 11,500 lbs. is its mean cohesive force.

Strength of beech	103	oak being = 100.
Stiffness	77	
Toughness	138	

Hence it appears that oak is superior in stiffness, but neither so strong nor so tough.

553. In North America two species of the beech are common—the White (*F. sylvestris*), and the Red (*F. ferrugina*). The tree of the white beech is more slender and less branching than that of the red; but according to Michaux its foliage and general appearance is magnificent. The perfect wood of this species bears a small proportion to the sap, and frequently occupies only 3 inches in a trunk 18 inches in diameter. It is therefore of little use except for fuel.

The red beech, which is almost exclusively confined to the north-eastern parts of the United States, and to the provinces of Canada, New Brunswick, and Nova Scotia, bears a close resemblance to the common European species (*F. sylvatica*). The wood is stronger, tougher, and more compact than that of the white kind, but it is so liable to the attacks of insects that its use in domestic furniture is rare. It is, however, very durable when constantly immersed in water.

Alder.

(*Alnus glutinosa.*)

554. The alder-tree is a native of Europe and Asia, growing in wet grounds and by the banks of rivers. The tree seldom exceeds 40 feet in height, and 24 inches diameter,

except in very favourable soils, when it has been known to attain a height of 60 feet, with a diameter of 30 inches.

The wood is extremely durable in water or wet ground. Vitruvius has remarked, that in a wet state it will sustain the weight of very heavy piles of building without risk of accident; and that the whole of the buildings at Ravenna, which is situate in a marsh, were founded upon piles of this wood.* Evelyn says, he finds they used it under that famous bridge at Venice, the Rialto, which was built in 1591, or 280 years ago. But it soon rots when exposed to the weather, or to damp; and in a dry state it is much subject to worms.

On account of the durability of alder in water, it is esteemed valuable for piles, planking, sluices, pumps, and in general for any purpose where it is constantly wet. And for such purposes it has been much cultivated in Holland and Flanders. It is also used for turners' wares and other light purposes. Our ancestors used it for scaffolding.†

The colour of alder is reddish yellow, of different shades, and nearly uniform. The texture is very uniform, with the larger rays of the same colour as the wood, therefore not very distinct, nor producing a flowered appearance when wrought.

It is soft, and works very easily; would cut well in carving, and make very good models for casting from.

The cohesive force of a square inch of alder varies from 5000 to 13,900 lbs.; its modulus of elasticity is 1,086,750 lbs. for a square inch; and a cubic foot weighs from 34 to 50 lbs. in a dry state.

Strength of alder	80	oak being = 100.
Stiffness	63	
Toughness	101	

* 'Vitruvius,' book ii., chap. ix., and book iii., chap. iii.

† Britton's 'Architectural Antiquities,' vol. iii., p. 31.

Plane-tree.

(Genus *Platanus*.)

555. Of the plane-tree there are several species. The most common are the Oriental Plane and the Occidental Plane.

556. The Oriental Plane (*Platanus orientalis*) is a native of the Levant, and other eastern countries, and is considered one of the finest of trees. It attains about 60 to 80 feet in height, and has been known to exceed 8 feet in diameter. Its wood is much like beech, but more figured, and is used in England for furniture, &c. The Persians employ it for their furniture, doors, and windows, and various other purposes of carpentry.

557. The Occidental Plane (*Platanus occidentalis*) is a native of North America, and is perhaps one of the largest of the American trees; on the fertile banks of the Ohio and Mississippi some of the trees exceed 12 feet in diameter: the usual size is, however, about 3 or 4 feet in diameter. It is sometimes called water-beech, button-wood, and sycamore; but the wood called sycamore in this country is a species of maple. The wood of the occidental plane is harder than that of the oriental kind; but the former is the most common in Britain.

The colour of the wood of the occidental plane-tree is nearly the same as that of beech, and it also closely resembles it in structure; it differs in the larger medullary rays, as in the plane the rays are more numerous, producing very beautiful appearances when properly cut. It works easily, and stands moderately well, but is short-grained and easily broken.

The cohesive force of a square inch is about 11,000 lbs.; its modulus of elasticity is 1,343,000 lbs. per square inch; and it weighs from 40 to 46 lbs. per cubic foot when dry.

Representing the strength of oak by	100,	that of plane-tree will be	92
„ stiffness „	100	„	78
„ toughness „	100	„	108

The wood of the occidental plane is very durable in water, and on that account the Americans use it for wooden quays in preference to any other kind.

Sycamore.

(Acer pseudo-platanus.)

558. The Sycamore, or Great Maple, generally called the "Plane-tree" in the north of England, is a native of the mountains of Germany, and is very common in Britain.

It is a large tree, and of quick growth; it thrives well near the sea. According to Hassenfratz, the mean size of its trunk is about 32 feet in length, and 29 inches in diameter. Evelyn says, that in Germany they have a better variety than the one which grows in Britain.

The wood is durable in a dry state when it can be protected from worms, but it is equally as liable to be destroyed by them as beech. It is used chiefly for furniture, and the white wood of this tree is valuable for many ornamental articles.

The colour of sycamore is generally of a brownish white; sometimes of a yellowish white, or nearly white in young wood, with a silky lustre. Its texture is nearly uniform, and the annual rings not very distinct. Its larger ravs are small and close, and perhaps it might be more correctly described as having distinct smaller medullary rays, and no larger rays, the flowers presented by the grain are small, with a minute dappled appearance. The wood is sometimes beautifully curled. In large trees the wood is usually tainted and brittle. It is in general easy to work, being less hard than beech.

The cohesive force of a square inch varies from 5000 to 10,000 lbs.; its modulus of elasticity is 1,036,000 lbs. for a square inch. A cubic foot of sycamore weighs from 34 to 42 lbs. when dry.

Strength of sycamore	81	oak being = 100.
Stiffness "	59	
Toughness "	111	

DIVISION II.

559. No distinct large medullary rays.

Sub-div. I.—Annual rings distinct, one side porous, the other compact.

CHESTNUT.

(*Castanea vesca.*)

560. This species, which is commonly called the "Sweet" or Spanish Chestnut, is supposed to be a native of Greece and Western Asia, but grows wild in Italy, France, and Spain. It is also to be found in the north of Africa and in the woods of North America, but it is said not to be a native of Britain, although grown in the country from a very early period. It is thought by some to have been introduced by the Romans.

Under favourable circumstances of soil and situation the tree often attains in the course of fifty or sixty years a height of 60 or 70 feet, with a stem of from 4 to 6 feet in diameter. The mean size of the trunk or stem, however, according to Hassenfratz, is about 44 feet in length and 37 inches in diameter.

As a tree the chestnut is one of the most long-lived in Europe, sometimes enduring for more than 1000 years; but unlike oak, which gains strength and durability by age, after it arrives at about the age of fifty years it begins to deteriorate at the heart, becoming what is termed "ring shaken," the annual layers or circles at the centre separating from each other, which renders the wood of little value. Until, however, decay actually commences in the heart, the wood

is of excellent quality, and for most purposes where durability is required equal to oak, particularly in young trees, owing to the early period at which it becomes matured as well as from the very small proportion of sap-wood which it contains. Marshall states that hop-poles of this wood last longer than any other;* and in palings, stakes, gate and other posts it has been known to last from twenty to thirty years, which is longer than most woods do in such situations.

Mr. Kent has observed a post of chestnut taken up sound after having stood above forty years.† And Miller says it will endure longer than elm to convey water underground.

Chestnut is useful for the same purposes as oak, but the wood of old trees should not be used in any situation where an uncertain load is to be sustained, as it is brittle; and as Evelyn states, often makes a fair show outwardly when it is decayed and rotten within. According to Belidor, it soon rots when built into walls, therefore the ends of joists formed of this wood should have a free space left round them.

The wood of the chestnut is nearly of the same colour as that of the oak. In old wood the sap-wood of chestnut is whiter and the heart-wood browner; but it is so much like oak in appearance that in old buildings they have been mistaken one for the other. Sir H. Davy says, "they may be easily known by this circumstance, that the pores in the alburnum of the oak are much larger and more thickly set, and are easily distinguished by the naked eye, whilst the pores in the chestnut require a magnifying glass to be seen distinctly."‡

Chestnut has none of the larger medullary rays, which is a more decided difference, and renders it easy to be known from oak, whether the wood be old or not, particularly when cut in

* 'Rural Economy of the Southern Counties,' vol. i., p. 216.

† 'Trans. Soc. of Arts,' vol. x, p. 30.

‡ 'Agricultural Chemistry,' p. 222, 4to edit.

the plane of these laminæ. It may also be known from oak by its not becoming black when in contact with iron.

The wood is hard and compact; when young it is tough and flexible, but when old it becomes brittle and shaky. It does not shrink or swell so much as other woods, and it is easier to work than British oak.

The cohesive force of a square inch of chestnut varies from 9570 to 12,000 lbs. when dry. The weight of a cubic foot of dry timber is from 43 to 54·8 lbs.

The properties as determined from a piece of young wood in a green state are as follows:—

		lbs.
Cohesive force of a square inch	=	8,100
Weight of the modulus of elasticity per square inch	=	924,750
,, a cubic foot	=	54·7

Strength of green chestnut ..	68	oak being = 100.
Stiffness ,, ..	54	
Toughness ,, ..	85	

The following are the results of experiments on two pieces of dry chestnut which had been cut from a tree of about thirty years old, and 11 inches in diameter, of rapid growth. The specific gravity was 0·535.

No.	Length of Bearing.	Scantling.	Load.	Deflection.	Remarks.
	inches.	inches.	lbs.	inches.	
1	30	1 × 1	85	0·5	A small knot near the middle caused this to break with less weight than it should have done.
,,	,,	,,	153	Broke suddenly	
2	24		163	0·5	This is a fair example of the strength, but it bent considerably, the last deflection noted being $2\frac{1}{2}$ inches.
,,	,,	,,	296	Broke suddenly	

According to the experiment on the second specimen, the cohesion of a square inch of Spanish chestnut is 10,656 lbs., and the modulus of elasticity for a square inch according to the first experiment is 1,147,500 lbs.; according to the second, 1,126,656 lbs.

Chestnut bends more than oak at the time of fracture, and is therefore tougher; this permits it to yield insensibly until every particle exerts its utmost force, and then it gives way suddenly, more after the manner of metals than of wood.

The belief which has so long and so generally prevailed that the roofing and main timbers of many of our ancient buildings were framed of this timber, is a remarkable feature in the history of chestnut; but the examination and repeated experiments that have of late years been made upon it have satisfactorily proved that the timber which was mistaken for chestnut was oak, and chiefly of the sessiliflora species.

It is also curious that the same belief in the use of chestnut in ancient buildings had for a long time prevailed in France until disproved by Buffon, and afterwards by d'Aubenton, who showed that the timber taken for chestnut was in fact that of the *Quercus sessiliflora*.

Ash.

(*Fraxinus excelsior.*)

561. The common ash is a native of Europe, the north of Asia, and is to be found in Great Britain, from the north of Scotland to the south of England, and almost in all cases on good deep soil. It is the most valuable of the genus *Fraxinus*.

The ash is a very rapid growing tree, and, like the chestnut, the young wood is much more valuable than that of old trees. No timber varies more with the soil and situation

than the ash. The mean size of the trunk is, according to Hassenfratz, 38 feet in length and 23 inches in diameter; but sometimes this tree attains an immense size.

Ash soon rots when exposed to either damp or alternate dryness and moisture, but is tolerably durable in a dry situation. Evelyn says, the best season for felling ash is from November to February, and that when felled in full sap it is very subject to the worm. The pores of ash cut in the spring are of a reddish colour, and such wood is much benefited by water-seasoning.

Ash is superior to any other British timber for its toughness and elasticity; and in consequence of these properties, it is useful wherever sudden shocks are to be sustained; as in various parts of machines, wheel-carriages, implements of husbandry, ship blocks, tools, and the like; being equally as useful in the arts of war as in those of peace, in ancient as well as in modern times:

> "From Pelion's cloudy top, an ash entire
> Old Chiron fell'd, and shap'd it for his sire."
>
> POPE'S *Homer*.

It is too flexible for the timbers of buildings, and not sufficiently durable.

The colour of the wood of old trees is oak-brown, with a more veined appearance, and the veins darker than in oak; sometimes the wood is very beautifully figured. The wood of young trees is brownish white with a shade of green.

Its texture is alternately compact and porous, the compact side of the annual rings being darker coloured, which renders them very distinct. It has no larger rays, and consequently it is without the flowered appearance possessed by other timber, such as oak.

It has neither taste nor smell, and is difficult to work, except the wood of old trees, which is of a more brittle nature.

The cohesive force of a square inch varies from 6300 to 17,000 lbs.; and the weight of its modulus of elasticity is about 1,525,500 lbs. per square inch. The weight of a cubic foot dry varies from 34 to 52 lbs.; when the weight of a cubic foot is lower than 45 lbs., the wood is that of an old tree, and will be found deficient both in strength and toughness.

Strength of ash	119	oak being = 100.
Stiffness "	89	
Toughness "	160	

It exceeds oak both in strength and toughness, and in young wood the difference is still more considerable.

Elm.

(Genus *Ulmus.*)

562. Of the Elm-tree there are five species now common in Britain; *viz.* the common rough-leaved elm, the cork-barked elm, the broad-leaved elm or wych hazel, the smooth-leaved or wych elm, and the Dutch elm.

The Rough-leaved Elm (*Ulmus campestris*) is common in scattered woods and hedges in the southern parts of England, and is also found very plentifully in France and Spain. It is a harder and more durable wood than the other species: it resists moisture well, and is therefore preferred for coffins. The tree often attains in England a height of 70 to 80 feet, with a stem of 4 feet in diameter.

563. The Cork-barked Elm (*Ulmus suberosa*) is very common in Sussex, but the wood is of an inferior kind.

564. The Broad-leaved Wych Elm (*Ulmus montana*), also called Wych Hazel, from its resemblance to the hazel-tree, is a native of Britain and other parts of Europe, and is more

cultivated in Scotland than the English elm. It is also cultivated in Ireland as a timber tree, but in England and on the continent of Europe it is not so much cultivated as the *U. campestris.* The tree is commonly found growing from 70 to 80 feet high, with stems of from 3 to 4½ feet in diameter.

565. The SMOOTH-LEAVED WYCH ELM (*Ulmus glabra*) is common in Herefordshire, Essex, the north and north-east counties of England, and also in Scotland. It grows to a large size, and is much esteemed. It is readily distinguished by its smooth, dark, lead-coloured bark, and by its leaves being nearly smooth on the upper surface. The wood is tough and flexible, and is said to be preferred for the naves of wheels.

566. The DUTCH ELM (*Ulmus major*) is a native of Holland; its wood is very inferior to the other species; indeed, Miller says it is good for nothing.

567. The Wych Elm is the largest tree, and the Dutch Elm the smallest. Hassenfratz states the mean size of the trunk of the elm-tree to be 44 feet in length and 32 inches in diameter. The trunk of the common rough-leaved elm is often rugged and crooked, and the tree is of slow growth. Marshall says the Vale of Gloucester produces some very fine elm-trees, but he has not described the species.

Elm has always been much esteemed for its durability in situations where it is constantly wet; and it is also said to be very durable in a perfectly dry state, but not when exposed to the weather. The piles upon which old London Bridge stood were chiefly of elm, and remained six centuries without material decay;* and several other instances of its durability in water have been noticed.

Elm is not useful for the general purposes of building, but from its durability in water it makes excellent piles and

* Hutton's 'Tracts,' vol. i., p. 119.

planking for wet foundations. It is also used for water-works, pumps, and for water-pipes before the introduction of cast iron. The naves of wheels, the shells of blocks for tackle, the keels and sometimes the gunwales of ships are made of elm.

The colour of the heart-wood of elm is generally darker than that of oak, and of a redder brown. The sap-wood is of a yellowish or brownish white, with pores inclined to red. Elm is in general porous, and cross-grained, sometimes very cross-grained, and has no large medullary rays. It has a peculiar odour. It twists and warps much in drying, and shrinks considerably both in length and breadth. Elm is difficult to work, but is not liable to split, and bears the driving of bolts and nails better than any other timber. The timber of the English elm is generally considered the best; that of the wych elm is equally as good, but the Dutch elm is very inferior.

The cohesive force of a square inch of elm varies from 6070 to 13,200 lbs.; and the weight of its modulus of elasticity for a square inch is about 1,343,000 lbs. The weight of a cubic foot when dry is from 34 to 47 lbs.; and when merely seasoned, from 36 to 50 lbs.

Strength of elm	82	oak being = 100.
Stiffness "	78	
Toughness "	86	

According to the experiments of Mr. Couch, elm shrinks *one-forty-fourth* part of its width in seasoning.

568. In America the elm is also to be found, and is used for many of the purposes to which the European species are applied.

The common AMERICAN ELM (*Ulmus Americana*) grows in the low woods of North America, from New England to Canada, where it attains a height of 80 to 100 feet. The wood is not considered so good as the European species.

569. The Canada Rock or Mountain Elm (*Ulmus racemosa*), so called from the rocky places on which it grows, supposed to be a variety of the last, is common to Canada and the northern states of America. It is used, as a substitute for American white oak, for boat-building in the Royal Dockyards of England, for which it is well adapted; but it is a timber very liable to shrink, and it soon becomes shaky when exposed to the sun and wind. When kept in a dry and confined place, the rock elm will sometimes become so perished as to resemble cork.

The annual rings are very close, and the fibres porous, and the wood is remarkable for its free and clear texture throughout its entire length, even up to 40 or 50 feet. It is therefore very flexible.

The weight of a cubic foot while green is about 55 lbs., and when seasoned about $47\frac{1}{2}$ lbs. It shrinks about the *one-twenty-fourth* part in width in seasoning.

570. The Slippery Elm (*Ulmus fulva*) is a native of North America. The wood is of a darker colour than the *U. Americana*; it is also of an inferior quality, though much used for a variety of purposes.

Common Acacia.

(*Robinia pseudo-acacia.*)

571. The common Acacia, or American locust-tree, is a native of the mountains of America from Canada to Carolina. It is a beautiful tree, attains a considerable size, and is of very quick growth. According to Hassenfratz, the mean size of its trunk is 32 feet in length and 23 inches diameter.

The wood is much valued for its durability. Some of the houses built by the first settlers in New England of this wood still continue firm and sound; and in posts, stakes,

The colour of the wood of the acacia is of a greenish yellow, with a slight tinge of red in the pores. Its structure is alternately, nearly compact, and very porous, which marks distinctly the annual rings. It has no large rays, and therefore no flowered grain. It has no sensible taste or odour in a dry state. About the same degree of labour is required to work it that ash requires.

The cohesive orce of a square inch varies from 10,000 to 13,000 lbs.; and the weight of a cubic foot when seasoned is from 49 to 56 lbs. Its other properties, determined from young wood in an unseasoned state, are as under:—

Weight of the modulus of elasticity for a square inch, 1,687,500 lbs.

Strength of unseasoned acacia	..	95	oak being = 100.
Stiffness " "	..	98	
Toughness " "	..	92	

Hence in a dry state it would probably be superior to oak in these properties.

DIVISION II. (*continued*).

572. *Sub-div. II.* Annual rings not distinct; texture nearly uniform.

MAHOGANY.

(*Swietenia mahogani.*)

573. The mahogany tree is a native of the West Indies and the country around the Bay of Honduras in Central America. It is stated to be of comparatively rapid growth, arriving at maturity in about 200 years.

In the rich valleys among the mountains of Cuba, and

those that open upon the bay of Honduras, the mahogany tree, according to Rhind, expands to so great a size, divides into so many massive arms, and throws the shade of its shining green leaves, spotted with tufts of pearly flowers, over so vast an extent of surface, that it is difficult to imagine a vegetable production combining in such a degree the qualities of elegance and strength, of beauty and sublimity.* Its trunk often exceeds 40 feet in length, and 6 feet in diameter.

Unfortunately the finest mahogany trees are not in the most accessible situations: and as it is always exported in large masses, the transportation of it for any distance overland is so difficult, that the very best trees both in the islands and on the mainland, those that grow in the rich inland valleys, defy the means of removal possessed by the natives. The mahogany tree of Honduras is cut down at two periods in the year, namely, Christmas and autumn. It is cut off at about 12 feet from the ground, the woodmen having a stage to work from. The trunk furnishes wood of the largest dimensions, but for ornamental purposes the branches are preferred, owing to the grain being closer and the veins more variegated.

Mahogany was first brought to London in the year 1724.

In a dry state mahogany is very durable, and not liable to the attack of worms, but it does not last long when exposed to the weather.

It is a kind of wood that would make excellent timbers for floors, roofs, &c., but on account of its costliness its use is chiefly confined to furniture, doors for rooms, and a few other articles of joinery, for which purpose it is the best material known. It has sometimes been used for window-sashes and parts of window-frames, but from not standing the weather well it is not so fit for these purposes.

Mahogany has also been used extensively in the framing of machinery for cotton-mills.

* 'Hist. of the Vegetable Kingdom.

The colour of mahogany is a reddish brown, of different shades, and various degrees of brightness; sometimes it is yellowish brown; often very much veined and mottled, with darker shades of the same colour.

The texture is uniform, and the annual rings are not very distinct. It has none of the larger medullary rays, but the smaller rays are often very visible, with pores between them. In the Jamaica wood these pores are often filled with a white substance, but in the Honduras wood they are generally empty.

It has neither taste nor smell, shrinks very little, and warps or twists less than any other kind of wood.

The variety called Spanish mahogany is imported from Cuba, Jamaica, Hispaniola, and some other of the West Indian Islands, and in smaller logs than that from Honduras.

The size of the logs is in general about 20 to 26 inches square, and about 10 feet in length. The Spanish mahogany is close-grained and hard, generally of a darker colour than the Honduras; it is free from black specks, and is sometimes strongly figured; the pores appear as if chalk had been rubbed into them.

The Honduras mahogany is imported in logs of a larger size, namely, from 2 to 4 feet square, and 12 to 14 feet in length; sometimes planks have been obtained 6 or 7 feet wide.

The grain of Honduras mahogany is generally very open and often irregular, with black or grey spots. The veins and figures are frequently very fine and showy; the best kind is that which is most free from grey specks and of a fine golden colour. It holds the glue better than any other wood.

The cohesive force of a square inch of Spanish mahogany is 7560 lbs., and of Honduras mahogany 11,475 lbs.

The weight of the modulus of elasticity of Spanish mahogany is 1,255,500 lbs. for a square inch, and for Honduras 1,593,000 lbs.

The weight of a cubic foot of mahogany is from 35 to 53 lbs.

	Spanish mahogany.	Honduras.	
Strength	67	96	oak being = 100.
Stiffness	73	93	
Toughness	61	99	

574. There are three other species of the genus *Swietenia* besides the mahogany tree, two of them natives of the East Indies, *viz.* the *S. febrifuga*, which is a very large tree growing in the mountainous parts of Central Hindostan, and rising to a great height, with a straight trunk, which towards the upper part throws out many branches. The head is spreading, and the leaves have some resemblance to those of the American species. The wood is of a dull red colour, not so beautiful as the Spanish or Honduras mahogany, but much harder, heavier, and more durable.

The natives of India consider it the most lasting timber that their country produces, and therefore use it upon every occasion where they wish to combine strength with durability.

575. The other East Indian species is the *S. chloroxylon*, which is chiefly found in the mountains of the Sircars, that run parallel to the Bay of Bengal, to the north-east of the river Godavery. The tree does not attain the same size as either of the former species, and the appearance of the wood is different. It is of a deep yellow, nearly of the same colour as box, from which it does not differ much in durability. The grain is close and the wood heavy.

576. Another species, called the AFRICAN MAHOGANY (*S. Senegalenis*), is brought from Sierra Leone: it is a hard and durable wood, and is much used for purposes which require strength, hardness, and durability. If, however, the heart of the tree is crossed or exposed in cutting or trimming the timber, it is very liable to premature decay.

Walnut.

(*Juglans regia.*)

577. The Royal or Common Walnut-tree is a native of Persia and the northern parts of China. It is found in most parts of Europe as far as 55° north latitude. The walnut-tree was formerly much cultivated in Britain for its wood, which was highly prized before the introduction of mahogany, and to which it is still preferred by many people of taste, who consider its colour to be superior to the red brown of mahogany. In many parts of the continent of Europe this wood is still extensively used for articles of domestic furniture, and both there and in England for the stocks of guns and other fire-arms. The tree thrives best when planted in a dry, deep, and strong loamy soil, rather light than heavy. It will not succeed on heavy or cold-bottomed land. It grows rapidly until it has attained a considerable size. In favourable soils and sites in this country it frequently attains a height of 60 feet, with a stem of 30 or 36 inches in diameter; but it has been known to reach a height of 80 feet, with a stem of 3½ or 4 feet in diameter.

When the tree is young, its timber is soft and white, and inferior to that of most other young trees; but after it has attained the age of about fifty years it becomes hard and solid, and the colour becomes darker as it advances in age. After sixty years is probably the best time for cutting it down; the wood is then in the best condition for the cabinet-maker or gun-stock manufacturer.

Trees that are intended to be cultivated for the sake of their timber should not be transplanted, as it injures the tap-root, and causes the tree to become branchy.

Walnut, on account of its scarcity, is seldom used for the purposes of building; indeed, it is of too flexible a nature for beams, though it appears to have been used by the

ancients for that purpose. Pliny observes that it has the good property of giving warning by cracking before it breaks; hence when the baths of Antendros failed, the bathers were alarmed in time to save themselves.

The wood of the walnut-tree is durable and not liable to be destroyed by worms. The heart-wood is of a greyish brown, with blackish-brown pores, often much veined, with darker shades of the same colour; the sap-wood is greyish white. The colours are much brightened, and the veins rendered more distinct by oiling. Its texture is not so uniform as that of mahogany, the pores being somewhat more thickly set on one side of the annual ring. It has no large rays nor flowered appearance. It has a slightly bitter taste when green, and a perceptible odour. It does not work so easily as mahogany, but may in general be brought to a smoother surface. It shrinks very little.

The cohesive force of a square inch of walnut varies from 5360 to 8130 lbs.; its modulus of elasticity for a square inch is 837,000 lbs. in a green state; the weight of a cubic foot varies from 40 to 48 lbs. in a dry state.

Strength of common walnut	..	74	oak being = 100.
Stiffness ,,	..	49	
Toughness ,,	..	111	

These properties were ascertained from a green specimen; the strength and stiffness would be greater in a dry state.

578. The Hickory or White Walnut (*J. alba*) is very common in most parts of North America. It is a large tree, rising to a great height, perfectly straight, and of nearly uniform thickness for a considerable part of its length. The trunk sometimes exceeds 3 feet in diameter. One part of the wood is more porous than that of the common walnut, but the other is more compact. The wood of young trees is extremely tough and flexible, making excellent handspikes, shafts and poles of wheel-carriages, and fishing-rods.

579. The Black Virginia Walnut (*J. nigra*) is also found in America, from Pennsylvania to Florida. The tree is large, and the wood is heavier, stronger, and more durable than that of the European walnut. It is of a fine grain, beautifully veined, and is susceptible of a high polish. It is well adapted for naval purposes, as it is said not to be liable to the attack of sea-worms in warm latitudes. The heart-wood, when properly seasoned, is strong and tough, and not liable to twist or warp.

The black walnut is extensively used in America for various purposes, where it is highly esteemed as the most valuable of the walnut-tree species.

Poplar.

(Genus *Populus.*)

580. Of the poplar-tree there are several species, five of which are common in England, *viz.* the White Poplar (*P. alba*), the Black Poplar (*P. nigra*), the Grey Poplar (*P. canescens*), the Aspen or Trembling Poplar (*P. tremula*), and the Lombardy Poplar (*P. dilatata*). In America there are two species which are common, *viz.* the Ontario Poplar (*P. macrophylla*), and the Black Italian Poplar (*P. acladesca*).

There is not much difference in the wood of any of these species. The colour is either a yellowish or brownish white, one side of the annual rings being a little darker than the other, which renders the growth of each year visible. The tree grows rapidly; the wood is generally soft and light in weight; that of most of the species proves durable in a dry state agreeable to the woodman's adage—

> "Cover me well to keep me dry,
> And *heart* of oak I do defy."—Cragg.

It makes very good flooring for bedrooms, and places not subject to much wear, and it does not catch fire readily; or,

as Evelyn has it, "the poplar burns untowardly, and rather moulders away than maintains any solid heat." Vitruvius has justly observed of the poplars "that they are woods sufficiently strong for light purposes, being soft, white, easy to work, and well adapted for carving; but none of the species are fit for large timbers."

The wood is of uniform texture, and without the large medullary rays. It is not apt either to swell or shrink. Owing to its lightness it is much used for butchers' trays, packing-cases, and other work where weight would be objectionable.

The black, common white, or Abele, which is a variety of the white, and the grey poplar, are the most esteemed in England. The Lombardy poplar is the lightest and most inferior, but it is sometimes recommended for cheese-rooms and farmhouses in general, because neither mice nor mites will attack it.

These species frequently attain a height of 70 or 80 feet, with stems of 3 or 4 feet in diameter. The Aspen Poplar seldom, under ordinary circumstances, attains a greater height than 40 or 50 feet, with a stem of 12 to 15 inches in diameter. The wood of this species, when cut up, is short-grained, and very easily broken when submitted to any strain.

The Ontario poplar is said to be a native of New Hampshire, in the United States of America. It grows very rapidly, having been known in some parts of the country to attain a height of 50 feet in fourteen years.

The Black Italian Poplar is found in Canada and the United States, where it seldom attains a greater height than about 60 feet. In England it attains a much greater height.

The poplar-tree is largely cultivated by the Dutch, in consequence of its being well adapted to their moist soil and climate.

The, cohesive force of a square inch of common white

poplar is from 4596 to 6641 lbs., and the other will not differ much from it. The weight of the modulus of elasticity for a square inch is,

	lbs.
For Abele white poplar	1,134,000
Lombardy ,, ...	763,000

The weight of a cubic foot when dry is

	lbs.
For Abele white poplar	32
Common ,, ...	33
Aspen and black ditto	26
Lombardy ditto	24

	Abele.	Lombardy.	
Strength	86 ..	50	oak being = 100.
Stiffness	66 ..	44	
Toughness	112 ..	57	

Teak.

(*Tectona grandis.*)

581. The Teak-tree is a native of the dry and elevated districts of the south of India; chiefly those situated along the Malabar and Coromandel coasts, as well as of Burmah, Pegu, Java, Ceylon, and other parts of the East Indies. It is of rapid growth, with a tall straight trunk, often more than 150 feet high, and copious spreading branches.

The wood of the teak-tree resembles oak in colour and lustre, and is by far the most useful timber in India. It is light, easily worked, and, though porous, is strong and durable. It requires little seasoning, and does not shrink much. It is said to afford a kind of tar, and the wood being of rather an oily nature does not injure iron. It is the best wood that can be used for carpentry or other purpose where strength and durability are required. For ship-building it is considered superior to all other timber.

According to Mr. Fincham, the teak brought from Moul-

mein is in various respects superior to that from Malabar "In India, where the opportunities of comparing them have been more ample than in the dockyards of this country, the Moulmein teak is stated to be of less specific gravity, of greater flexibility, and freer from knots and rindgalls than that of Malabar; it is also of a lighter colour. It grows to an immense size in the forest, and trees are sometimes cut of 8 or 9 feet in diameter; but most of such trees being unsound, smaller ones of 18 inches diameter and under are preferred. The largest mast pieces of this teak run to about 85 feet in length and about 8 or 9 feet in girth."*

Malabar teak has also been extensively used for ship-building at Bombay. It grows in the teak forests along the western side of the Ghaut and adjoining mountains, where numerous streams afford water-carriage for the timber. It is stronger than the Moulmein teak. According to Dr. Roxburgh there is a variety of teak that grows on the banks of the Godavery River, the wood of which is beautifully veined, closer grained and heavier than that of the other varieties, and well adapted for furniture.

The Vindhyan teak is much superior to that of Pegu both in strength and beauty. The specific gravity is about the same, but the deeply-marked and wavy irregular veins of the Vindhyan tree afford much handsomer cabinet-wood than the straight-grained and faintly-marked timber of Pegu.†

The teak from Johore is perhaps the heaviest and strongest of the species, and is said to be well adapted for permanent sleepers on railways, beams, piles, and engineering purposes generally. Piles in a comparatively good state of preservation exist on the site of the old town of Johore, which has been abandoned upwards of 100 years.

There is no timber so useful for the purposes of the car-

* 'Outline of Ship-building.'

† Roorkee, 'Treatise on Civil Engineering,' vol. i.

penter as teak; it possesses the qualities of size, strength, and durability in an eminent degree. As regards its capabilities of resisting the attacks of worms and insects it stands unrivalled. At St. Helena, according to Mr. Hounslow, when specimens of every other kind of wood that had been sent to the island in great variety, some even strongly impregnated with poisonous substances, failed to escape the destructive jaws of the most formidable species of the white ant, the teak alone remained uninjured (see Art. 485).

The cohesive force of teak-wood varies from 13,000 to 15,000 lbs. per square inch. The weight of its modulus of elasticity is 2,167,000 lbs. per square inch, according to Barlow's experiments; and the weight of a cubic foot of dry Malabar teak is about 45 lbs., of Moulmein teak 56 lbs., and Johore teak $62\frac{1}{2}$ lbs.

Strength of teak	.. ..	109	oak being = 100.
Stiffness ,,	.. ..	126	
Toughness ,,	.. ..	94	

Turtosa, or African Oak.

(*Oldfieldia Africana.*)

582. This timber, which has been imported in considerable quantities from Sierra Leone, is used for the same purposes as oak, but chiefly for ship-building. The colour of the wood is a moderately deep yellow or greyish brown. The texture is uniform; the annual rings are not very distinct, but the smaller medullary rays are strong and numerous. The wood is dense, hard, and brittle; the taste bitter; but the seasoned wood has no sensible smell. It appears to split much internally while seasoning, and is liable to the attacks of worms and insects. In the form of plank it is apt to warp, and it swells with moisture, which in drying out again causes the timber to split.

The Turtosa can be obtained in balks of considerable length free from knots.

According to the author's experiments made in 1821 the cohesive force of a square inch of Turtosa is 17,200 lbs., and the weight of a cubic foot dry is from 58 to 61 lbs.

The weight of the modulus of elasticity for a square inch is 1,728,000 lbs.

A bar 1 foot long between the supports and 1 inch square, broke with 954 lbs. applied in the middle, and bent $\frac{1}{480}$ of its length, or one-fortieth of an inch by a weight of 100 lbs.

According to experiments made by Sir F. Smith, the cohesive force of a square inch of Turtosa is 21,000 lbs., that of oak being 19,900 lbs., and fir 12,000 lbs.

The resistance to compression of specimens 4 feet long and $1\frac{1}{2}$ inch square, was for Turtosa and English oak as follows:—

	lbs.	Mean.
Turtosa broke with	9194	9278
" "	9362	
English oak broke with ..	4154	4938
" " ..	5722	

Resistance to crushing of short specimens of Turtosa made by Mr. Renton:—

Length.	Scantling.	Split with	Crushed with	Strength per square inch.
inches.	in. square.	lbs.	lbs.	lbs.
4	2	30,080	33,920	8480
4	$1\frac{7}{8}$	30,080	34,563	9600
			Mean	9320

COLONIAL TIMBER.

India.

583. Sâl or Saul (*Shorea robusta*).—This is one of the most useful woods in India for the purposes of the carpenter, and is to be found chiefly along the foot of the Himâlaya mountains, and on the Vindhyan hills near Gaya, the best being obtained from Morung.

The wood of the saul is strong and durable, but rather coarse-grained, with particularly straight and even fibre. It dries very slowly, and the wood continues to shrink for several years after other woods have become dry; therefore timbers of small scantling are very liable to warp in drying, unless some means be adopted to prevent it. Such is the size attained by this noble tree that the Nepal ferry-boats, which used to contain from ten to fifteen men, with horses and cattle, were hollowed out of single logs. It takes 100 years, however, for the tree to attain this size.

The saul wood is used chiefly for floor-beams, planks, and roof trusses, and it can be obtained in lengths of from 30 to 40 feet, and from 12 to 24 inches square.

The weight of a cubic foot is 61½ lbs. when seasoned, and 55 lbs. when perfectly dry.

The cohesive force of a square inch is 11,500 lbs.; the crushing force per square inch is 8500 lbs.; and the breaking weight in the middle of a specimen, 1 inch square, supported at both ends, with a bearing of 1 foot, is 881 lbs.

584. Teak (*Tectona grandis*).—See description of timber used in England, Art. 581.

585. Deodar (*Cedrus deodara*).—This very nearly resembles the cedar of Lebanon. It is found on the Himâlaya mountains, at elevations of from 5000 to 12,000 feet. It is also found on all the higher mountains from Nepal up to

Cashmere. Trees have been found measuring from 150 to 200 feet high, and over 30 feet in circumference.

Specimens of the Deodar have been cultivated in England, where they have attained a height of upwards of 60 feet. The wood is extremely valuable for all purposes of carpentry, and is the kind most generally employed in the Punjab for building. The weight of a cubic foot is about 37 lbs., and the load on the middle required to break a specimen 1 foot long and 1 inch square, supported at both ends, is 520 lbs.

586. SISSOO, or SEESUM (*Dalbergia sissoo*).—This wood is found in several parts of India. In Rohilkund it grows to a height of about 30 feet, and from 1 to 3 feet in diameter. At Chandah it is said to attain a greater size than elsewhere.

Sissoo wood somewhat resembles the finer sorts of teak, but it is tougher and more elastic.

It is generally more or less crooked, and therefore not suited for beams, though very much used by the ship-builders of Bengal, and throughout India generally for joiners' work, for which purpose it is said to excel all other timber, as it unites strength and durability with a close and compact grain. It is also much used for furniture.

The wood is said to harden with age. The colour is a light greyish brown, with darker-coloured veins, and the pores nearly filled with dry resinous matter.

The weight of a cubic foot is 46½ lbs. The cohesive force of a square inch is 12,000 lbs.; and the breaking load on the middle of a specimen 1 foot long, between the supports, and 1 inch square, is about 700 lbs.

587. POON (*Calophyllum Burmanni*).—This wood is abundant in the Burman forests, in Southern India, and the Eastern Islands. It is a tall, straight tree, usually attaining about 6 feet in girth, and resembles a dull-coloured and greyish specimen of mahogany. It is used for the decks, masts, and yards of ships, for which it appears to be well

adapted, owing to its strength and lightness. The texture is coarse and porous, but uniform. It is easy to saw and work up; it holds nails well, but is not durable in damp situations.

The mean weight of a cubic foot, unseasoned, is about 55 lbs., and when seasoned about 40 lbs.

The cohesive force of a square inch is from 8000 to 14,700 lbs. The weight of the modulus of elasticity for 1 square inch is 1,689,800 lbs.

The specific gravity, and the relative strength, stiffness, and resilient power, compared with Riga "fir," which is taken as 1000, are as under:—

Specific Gravity.	Strength.	Stiffness.	Resilience.	
·579	1380	1270	1400	Barlow.
·647	1226	1230	1146	Fincham.
·613	1303	1250	1273	Mean.

Another species is the *Calophyllum agustifolium*, grown on the Malabar Hills, which is also said to furnish the "Poon" spars of commerce. The weight of a cubic foot when dry is 45 lbs., the cohesive force of a square inch is about 15,800 lbs., and the breaking weight on the middle of a bar 1 foot long and 1 inch square is 600 lbs.

588. TOON (*Cedrela toona*).—This wood, which is a kind of cedar, is one of the most esteemed in India, where it is in common use for joinery, and the manufacture of chairs, tables, and other kinds of furniture.

The tree sometimes measures 4 feet in diameter. The wood resembles mahogany in appearance, but the colour is of a duller red, and therefore of less brilliant hue.

It is not so strong as mahogany, though very durable. A cubic foot weighs about 35 lbs. The cohesive force of a square inch is 4992 lbs.; and the breaking weight in the

middle of a piece with a bearing 1 foot long and 1 inch square, supported at the ends, is 560 lbs.

589. MANGO (*Mangifera Indica*).—This is the well-known fruit-tree which is common throughout Asia, and is to be found in South America. The wood is cut up into planks, and used for a variety of purposes in India. It varies in quality, but as a rule is coarse and open grained, of a deep grey colour. The wood of full-grown trees, however, when thoroughly seasoned, makes excellent timber for common doors and door-posts. It is durable in dry situations, but decays rapidly when exposed to the weather, or immersed in water. Worms and the white ant attack it with avidity.

The Mango wood is light and strong, but liable to snap suddenly under a transverse load; a cubic foot weighs about 41 lbs.

The cohesive force of a square inch is 7700 lbs., and the transverse strength of a piece 1 foot long between the supports and 1 inch square, is 560 lbs., applied in the middle.

590. NEEM (*Azadarachta Indica*).—This is one of the commonest and hardiest trees in India, as well as the quickest in growth.

In the northern parts of the Gwalior territory it grows spontaneously, and attains a height of 40 to 50 feet, with a diameter of 20 to 24 inches.

The Neem seldom grows straight for more than 8 or 10 feet, above which it spreads into branches. Long beams are therefore not procurable; but the trunk and branches are cut into short thick planks, which are much used for the lintels of doors and windows. The heart-wood is of a light red colour, very like mahogany, which it much resembles in other respects.

The timber is hard and durable, but will not resist the attacks of insects. It is in great request among the natives for doors and door-frames, on account of its fragrant odour.

It takes a fine polish, is a good material for joiners' work where much strength is not required, for when thoroughly dry it becomes brittle, and is apt to snap at the joints. It is difficult to work.

The weight of a cubic foot is about 51 lbs. The cohesive force of a square inch is 6940 lbs., and the breaking weight in the middle of a piece 1 foot long between the supports and 1 inch square, is 600 lbs.

591. Anjilli (*Artocarpus hirsuta*).—This is a species of the bread-fruit tree, also called the "Jungle Jack," which is remarkable for the size of the stem. It is found in the forests of Bengal, Malabar, and in Burmah. The wood is strong, close-grained, and of a light yellowish-brown colour. As a wood for ship-building, it is considered to be next in value to teak. The weight of a cubic foot unseasoned is about 49 lbs., and when seasoned about 38 lbs. Selected specimens 1 foot long and 1 inch square will sustain a transverse load on the middle of 740 lbs., the cohesive force being about the same as teak.

Another species of the Jack fruit-tree is the *Artocarpus integrifolia*, which is found all over India. The wood when dry is brittle, and has a coarse, crooked grain. When first cut the wood is yellow, but it afterwards changes to various shades of brown. It is suitable for house-building, joinery, and cabinet work. It is somewhat heavier and stronger than the *A. hirsuta*, though not so valuable for purposes of carpentry.

592. Kanyin (*Dipterocarpus alatus*).—A magnificent tree, found chiefly in Pegu and the Straits, often growing to a height of 250 feet. The timber is hard and coarse-grained, of a light-brown colour and strong odour. It is excellent for every purpose of house-building; but it is not durable in moist situations. The weight of a cubic foot is about 45 lbs. when dry, and the transverse strength of a piece 1 foot long and 1 inch square is 750 lbs. on the middle.

Another species, the *D. turbinatus*, found chiefly in Assam, Burmah, and the Andaman Islands, is similar to the last, and is much used by the natives as planks, &c., in house-building.

593. Pynkado or Ironwood (*Inga xylocarpa*).—This is a valuable timber tree found throughout Southern India and Burmah. The wood is of superior quality—hard, close-grained, and durable; the colour is a very dark red. It is, however, heavy, not easily worked, and difficult to drive nails into. It is extensively used for bridge-building, posts, piles, &c., and will last, it is said, for six years in railway sleepers if judiciously selected and seasoned. The weight of a cubic foot is about 58 lbs. when dry. The cohesive force per square inch is about 16,000 lbs., and the transverse strength of a piece 1 foot long and 1 inch square is about 800 lbs. on the middle.

594. Pymma (*Lagerstrœmia reginæ*).—A tree found abundantly throughout the country, particularly in South India, Burmah, and Assam. The wood is used more extensively than any other except teak, particularly in boat-building, and as posts, beams, and planks in house-building. The weight of a cubic foot is about 40 lbs., the cohesive force the same as teak, and the transverse strength of a specimen 1 foot long and 1 inch square is about 640 lbs.

595. Rohun (*Soymida febrifuga*).—A large forest tree of Central and Southern India, furnishing a bright red, close-grained wood of great strength and durability. It has a fine straight grain, and although a very heavy wood, is not so difficult to work as might be imagined. It stands well when covered up underground or buried in masonry, but will not do so well when exposed to sun and weather. It is used for palisades and railway sleepers, as well as for the woodwork of houses. The weight of a cubic foot is about 66 lbs. The cohesive force of a square inch is 15,000 lbs., and the trans-

verse strength of a piece 1 foot long and 1 inch square is about 1000 lbs.

596. Mutti (*Terminalia coriacea*).—The tree is common in the forests of Central and Southern India. The wood is of a reddish-brown colour, hard, heavy, tough, and fibrous; close and even grained, though inclined to open in seasoning, it is rather difficult to work; the white ants will not touch it, and it is considered one of the most durable woods known. It is therefore in demand for beams, telegraph and other posts. The weight of a cubic foot is about 60 lbs. when dry, and the transverse strength of a piece 1 foot long and 1 inch square is about 860 lbs. on the middle.

There are several species of the *Terminalia*, most of them producing valuable wood for building purposes.

597. The Leguminosæ produces several timber trees useful for building and other purposes, besides the "Sissoo," described in Art. 586, among which are the *Pterocarpus marsupia*, called in India "Honay," from which gum kino is obtained. The wood is light brown, close-grained, strong, and very durable, but not easily worked. It is abundant in Southern India. Also the *Hardwickia binata*, of Central and Southern India, producing a strong, hard, and heavy wood of a red or dark colour, useful for posts, pillars, and piles.

Ceylon.

598. Jack, called also Ceylon Mahogany, is a species of *Artocarpus* similar to the "Anjilli wood" of India. It is of a light yellow colour when new, but afterwards changes to that of mahogany. The timber is in general use in the South-East and West Provinces. The weight of a cubic foot is about 42 lbs. when dry, and the transverse strength of a piece 1 foot long by 1 inch square is 600 lbs. on the middle. It is durable, and can be obtained in logs 21 feet long and 17 inches diameter.

599. Gal Mendora is much used for bridges and buildings, particularly for "reepers" (roof battens), and is considered one of the best for underground purposes. It is chiefly found in the West and South Provinces. The weight of a cubic foot is about 57 lbs., and the transverse strength of a piece 1 foot long and 1 inch square is about 700 lbs. on the middle. It can be procured in logs 22 feet long and about 13 inches diameter.

600. Tal, Palmira.—Is much used in the North and Eastern Provinces for rafters and roof battens. It is a strong and durable wood, weighing about 65 lbs. per cubic foot; the transverse strength of a piece 1 foot long and 1 inch square is about 800 lbs. on the middle.

601. Kaha Milila.—Grown chiefly in the South and West Provinces, and used for bridges and buildings. Weight of a cubic foot is 56 lbs.; transverse strength of a piece 1 foot long and 1 inch square, 760 lbs.

602. Hal Milila.—Grown in the North and East Provinces. Is used for buildings, carts, and oil casks; for the latter purpose it is the best in the island. A cubic foot weighs 48 lbs., and the transverse strength as last is about 840 lbs. The timber, however, is procurable mostly in small sizes, but it has been procured in logs 20 feet long and 14 inches diameter.

603. Mal Buruta, or Satinwood.—From the North and East Provinces. Is one of the most valuable woods in Ceylon, and is much used in superior buildings; is very durable, but hard to convert. From the great beauty of its grain it is much prized for furniture. It has been procured in logs 19 feet long and 20 inches diameter. The weight of a cubic foot is 57 lbs., and the transverse strength is 300 lbs. on the middle of a piece 1 foot long and 1 inch square.

Note.—In addition to the foregoing there are a great variety of useful and valuable woods employed throughout the country for building

and engineering purposes, a description of which can be obtained from a small pamphlet on the subject by Mr. Adrian De Mendis, published in Ceylon; also from Spons' 'Information for Colonial Engineers,' art. "Ceylon," by Abraham Deane, C.E.

Teak-wood, described in Art. 581, is also one of the principal timbers used both in India and Ceylon for building purposes.

Australia.

604. Iron Bark (*Eucalyptus siderophloia*, also *E. leucoxylon*).—This is a rugged-looking tree, found in most parts of the continent. It frequently attains a height of 100 to 150 feet, with a diameter of from 3 to 6 feet; but the usual size of the logs obtained in the market is from 20 to 40 feet in length and 12 to 18 inches square. The wood is straight in the grain, very dense and heavy, the colour a dark red; it is strong and durable, but extremely difficult to work, therefore not an economical wood in a country where labour is scarce. "The tree is generally sound, but liable to the defect of both heart and star shakes, and on this account is not usually very solid about the centre. The timber cannot be employed with advantage except in stout planks or large scantlings." *

The weight of a cubic foot when dry is 64½ lbs. Crushing force, in the direction of the fibres, of a cube 1 inch square and 1 inch high, 9921 lbs. Breaking load on the middle of a specimen 1 inch square with a bearing of 1 foot, is 1000 lbs.

605. Blue Gum (*Eucalyptus globulus*).—This tree, named from the bluish-grey colour of the young plants, is of rapid growth, and frequently attains a height of 150 to 300 feet, with a diameter at the base of 10 to 20 feet. It has lately obtained some notoriety in England and other countries on

* Laslett's 'Timber and Timber Trees.'

this side of the globe, owing to its supposed effects in drying up the soil and disinfecting the air of marshy districts. It is used in Australia for carpenters' work generally, and also for the spokes of wheels, &c.

The wood is of a yellow or light-reddish colour, hard and compact, and rather difficult to work. It is liable to split, warp, and shrink considerably in seasoning. The weight of a cubic foot when dry is about 60 lbs. The crushing force of a piece 1 inch square and 1 inch high is about 6700 lbs., and the transverse strength of a specimen 1 inch square and 1 foot long between the supports, loaded in the middle, varies from 550 to 900 lbs.

The Blue Gum is also abundant in the southern and south-western parts of Tasmania.

606. Stringy Bark (*Eucalyptus gigantea*, *E. obliqua*, or *E. macrorrhyncha*).—This is considered one of the best timber-trees in Australia for building purposes. The common name is taken from the coarse, fibrous character of its bark. The tree, which is found mostly on hilly ground, attains a height and diameter about the same as the Iron Bark. The wood is somewhat cleaner and straighter in the grain than most of the other gum-trees. The colour is a pale brown; is hard, heavy, strong, close and straight in the grain. It works up well for the various purposes to which it is applied, such as planking, beams, joists, and flooring. Like most other species of the same genus, the wood becomes more difficult to work after it dries; therefore it should be cut up, and even planed, as far as practicable, while green, which is frequently performed where the tree was felled. It shrinks considerably in drying.

The outside of the tree is the part which produces the best timber, as the inside or heart of most of the gum-trees is often hollow and decayed. The weight of a cubic foot when dry is about 56 lbs. The crushing force is about the same

as that of the blue gum, but the transverse strength is considered to be much less.

607. WHITE GUM (*Eucalyptus viminalis*).—Also called the SWAMP GUM, from its growing to perfection in humid situations. It is chiefly found in Tasmania, where it attains a size equal to any of the other gum-trees. The bark of the tree is white, hence the name. The wood is sometimes used for ship-building, but is especially valued for house-building, and for most of the purposes to which the Blue Gum is applied. The weight of a cubic foot is somewhat less than the latter, from which it differs not much in strength. A variety of the White Gum, called Tewart, found principally in Western Australia, is much valued where great strength is required, and weight would not be an objection.

The wood of the Tewart is both sound and durable, and shrinks comparatively little in seasoning. The grain is rather crooked and twisted, which renders it difficult to split or work. The colour is somewhat similar to the Blue Gum. Tewart is much heavier than the White Gum of Tasmania, being as much as 70 lbs. to the cubic foot, the crushing force of a square inch about 10,000 lbs., and the transverse strength of a piece 1 foot between the supports and 1 inch square, about 730 lbs. on the middle.

608. JARRAH, or Australian Mahogany (*Eucalyptus marginata*).—Found abundantly in Western Australia, where it grows to a height sometimes exceeding 200 feet, and is supposed by some persons to be of the same species as the "Flooded" or "Red Gum" growing in other parts of Australia, to which, however, it is superior in strength and in other properties. The colour is darker than the "Blue Gum," and approaches that of mahogany. It is hard, heavy, close in texture, and very durable in both fresh and salt water, if cut at the proper season before the rising of the sap. It was employed in the whaling jetty at Freemantle,

and found, after sixteen years, to be in as good condition as when first used. Timber grown on the hills appears to be superior to that grown on the plains.

Jarrah is said to have the valuable property of resisting the attack of sea-worms and white ants, which never penetrate beyond the outer or sap wood.

In Western Australia it is used for almost every purpose where a strong wood is required, particularly for ships, jetties, &c., and it is exported to India for telegraph posts and railway sleepers. The tree has a core of gummy matter in the centre, sometimes in a state of decay; this often limits the sizes into which it can be converted. Some logs may, however, be procured from 20 to 40 feet in length, and 11 to 24 inches square.

It shrinks and warps considerably, which renders it unfitted for floors or joiners' work; it is also considered somewhat deficient in tenacity. The weight of a cubic foot is a little over 62½ lbs.; it will therefore not float in water. The crushing force in the direction of the fibres of a piece 1 inch square and 1 inch high is about 7000 lbs., and the transverse strength of a piece 1 foot long between the supports and 1 inch square, is about 500 lbs. on the middle.

The Kari is another species of Eucalyptus growing in the same locality as the Jarrah, which it exceeds in strength, but is not quite so heavy, nor, for general purposes, so durable. It is said to attain a height of from 300 to 400 feet.

There appear to be several species of the Eucalyptus throughout Australia and Tasmania, such as the Messmate (*E. fissilis*), all of which more or less resemble the foregoing; and probably many of them will be regarded as the same, or mere varieties of the same species, when the flora of the country is better known and classified.

609. Oak (Genus *Casuarina*).—This is another hard wood tree. It does not grow so tall as the gum-trees, being seldom found more than from 40 to 60 feet in height, with a diameter of from 12 to 30 inches. The two species most used for building purposes in Australia are the *C. torulosa*, called the Forest Oak, and the *C. paludosa*, called the Forest Swamp Oak.

The forest oak is chiefly used for splitting into shingles, for which purpose it is better adapted than any other timber in Australia, as it may be split into slabs so thin as to appear almost as neat as slates.

The weight of a cubic foot is about 50 lbs. The crushing weight of a piece 1 inch high and 1 inch square is about 5500 lbs., and the transverse strength about 700 lbs.

Another variety, called the She-Oak (*C. quadrivalvis*), and the He-Oak (*C. suberosa*), are found in Tasmania, but used more for ornamental than building purposes. The height of the tree seldom exceeds from 20 to 30 feet, with a diameter at base of 12 to 18 inches. The weight is somewhat greater than the forest oak.

610. Huon Pine (*Dacrydium Franklinii*).—So called because it was first discovered on the banks of the Huon river. It is said to be abundant in portions of the south-western part of Tasmania, though scarce in other parts. The tree is said to grow to a height of 50 to 100 feet, with a diameter of from 3 to 8 feet; but ordinarily the timber cannot be had in much greater lengths than from 12 to 20 feet, but can usually be procured in logs up to 2 feet square. The timber is clean and fine-grained, not unlike some of the northern pine of Europe. It is closer grained and more durable than the white pine of America; it has an aromatic smell. The weight of a cubic foot is about 40 lbs.

611. Cedar (*Cedrela Australis*).—The Australian Red Cedar is supposed to be the same species as the *Cedrela*

toona of India. It somewhat resembles the Havannah cedar, but is of a coarser grain and of a darker colour, not unlike Honduras mahogany. It is chiefly used in Australia for joiners' work, such as doors, sashes, &c., and also for boat-building.

Like mahogany, it is usually brought into the market in short thick logs. The weight of a cubic foot when dry is about 35 lbs., and the transverse strength of a specimen 1 foot long between the supports and 1 inch square, when loaded on the middle, is about 471 lbs.

612. Morton Bay Pine (*Araucaria Cunninghami*).*—This is a well-known tree, found in great numbers in Queensland, growing to a height of over 150 feet, with a diameter of about 5 feet. It yields spars from 80 to 100 feet long. The wood is straight-grained, tough, and tolerably free from knots, is excellent for joiners' work, and is remarkable for the peculiar figure set up, which resembles drops of rain in general effect, not easily to be described. The colour is similar to that of the yellow pine used in England. It is not so durable as the latter, is very liable to the attacks of sea-worms and white ants; the sap-wood appears to be peculiarly liable to rot.

In Queensland it is used for flooring-boards as well as for building purposes generally; and as it splits easily it is also used as shingles for roofing. It holds nails and screws well. The weight of a cubic foot when dry is about 45 lbs.

613. Norfolk Island Pine (*Araucaria excelsa*).—This tree is a native of Norfolk Island and Australia. In the former place it is found growing to a height of over 200 feet, with a diameter of 10 feet, and has been known to reach the height of 267 feet, with a diameter of 12 feet for nearly 80 feet of

* By Mr. William Spon, who resided for a short time in Queensland.

its length. The wood is white, tough, and close-grained, containing a large quantity of turpentine. The few trees of this species that were felled in Australia were found diseased at the bottom of the trunk and under the bark; but the timber when sound is well adapted for indoor work, and will vie with oak for many purposes in building. It is considered very durable.

New Zealand.

614. Kauri (*Dammara Australis*), see description on p. 430.—According to Mr. Laslett,* the timber is generally sound and free from many of the defects of the northern pines, and it is much more durable. It is strong, clean, fine, close, and straight in the grain, shrinks very little, and stands well after seasoning. From Mr. Laslett's experiments the transverse strength of a piece 1 foot long between the supports and 1 inch square, is about 611 lbs. in the middle. The cohesive force of a square inch being only 4543 lbs., which is much below that of other experimentalists; according to the same writer, the crushing strength of a short specimen 1 inch square did not exceed 7840 lbs.

615. Totara (*Podocarpus totara*).—This tree is found in the northern and southern islands, where it is rather abundant. It attains a height of about 80 feet, with a diameter of from 2½ to 3½ feet, and occasionally trees have been known to measure over 20 feet in circumference. The timber can be obtained in logs from about 12 to 20 inches square, and up to 40 feet in length. The wood is of a reddish colour, easily worked, straight and even in the grain, does not warp much, but is brittle and apt to shrink if not well seasoned; it splits very clean and free, and hence is valued for shingles,

* 'Timber and Timber Trees.'

which are considered more durable than the kauri or other pines. The tree has very little sap-wood, but it is subject to decay in the heart. It is used for flooring and joiners' work generally. In its green state the wood is heavy, but when dry the weight of a cubic foot is about 40 lbs. The transverse strength of a specimen 1 foot long between the supports, and 1 inch square, is 570 lbs. in the middle. It is much used by the colonists in the construction of their houses

616. There are several other valuable timber trees found in New Zealand, among which are the RATA (*Metrosideros lucida*), a hard wood which yields timber from 12 to 30 inches square and from 20 to 25 feet in length. The wood is of a dark-red colour, very dense and solid, with little or no sap-wood. The weight of a cubic foot when dry is about 65 lbs. The MIRO (*Podocarpus ferruginea*), a brownish-coloured wood, yielding timber from 15 to 30 inches square and 20 to 30 feet in length. It is useful for internal carpenters' and joiners' work, but it is not durable in outside work. The weight of a cubic foot when dry is about 46 lbs. BLACK PINE (Matai) *Podocarpus spicata.* This closely resembles 'Miro,' but is much more durable, and is used for all purposes where strength and solidity are required. The weight of a cubic foot when dry is about 40 lbs., and the transverse strength of a specimen 1 foot long and 1 inch square varies from 420 to 800 lbs. in the middle. WHITE PINE (Kahikatea) *Podocarpus dacrydioides.* This tree yields timber up to 40 feet in length, and from 24 to 40 inches square, the smaller sizes containing much sap-wood. It is a straight-grained, soft, and flexible wood, not much given to warping or excessive shrinkage, which renders it well adapted for flooring-boards and joiners' work generally. It is considered by the local tradesmen to be superior, when properly seasoned, to Baltic white deal for the interior work of houses.

The sap-wood is of a dull white colour, and the heart-wood a pale yellow. In outside work, where exposed to damp, it decays rapidly. The weight of a cubic foot when dry is about 30 lbs., and the transverse strength of a specimen 1 foot long and 1 inch square, is about 620 lbs. in the middle. The TANAKAHA (*Podocarpus asplenifolius*), a light-coloured wood, close and straight in the grain, yielding timber 10 to 16 inches square and 20 to 40 feet in length. The RIMU or RED PINE (*Dacrydium cupressinum*), the colour of which varies from light yellow to brown. The wood yields timber up to 30 inches square and 45 feet in length. It is much used in house-framing and carpenters' work, but is not so well adapted as "white pine" for joiners' work, being harder and given to shrink more irregularly. The weight of a cubic foot when dry is about 40 lbs.

CEDAR (*Libocedrus bidwillii* or *L. doniana*). This tree, which grows chiefly on the mountain ranges along the coast, attains a height of from 60 to 80 feet, with a clear trunk of from 20 to 40 feet, and from 2 to 3 feet in diameter. The wood is a dark-red colour, straight-grained and solid, but rather weak, as compared with other New Zealand timbers. The transverse strength of a specimen 1 foot long and 1 inch square, supported at the ends, being only about 400 lbs. on the middle. The weight of a cubic foot when dry is about 30 lbs. The timber is chiefly used for fencing-posts, house-blocks, piles, and railway sleepers. It is also suitable for ordinary house-framing, and other purposes where great strength is not required.

RED BIRCH (*Fagus fusca*) and the SILVER BIRCH (*Fagus menziesii*) are also useful woods for carpenters', joiners', and other purposes. The former weighs about 45 lbs. and the latter about 35 lbs. per cubic foot, when dry.*

* 'The Building Materials of Otago,' by W. N. Blair.

SOUTH AFRICA.*

617. The timber trees of the Cape Colony and Natal are chiefly evergreens. Their wood is dry and tough, and worked with more or less difficulty. Owing to the dryness of the soil and climate it is very liable to warp and twist in seasoning. Some descriptions shrink longitudinally as well as transversely, and with few exceptions the timber is not procurable in logs of more than 12 to 15 inches in diameter.

For these reasons European or American timber is used in preference to native in the larger towns, and in the neighbourhood of sea-ports. East Indian teak is also used for external doors and sashes.

Very few reliable experiments have been made on the timber grown in the colony. A fine collection of specimens are however to be seen in the Museum at Cape Town.

618. The following Table shows the most important kinds of wood used in the South African Colonies for building and other purposes :—

Dutch and English Common and Botanical Names.	Native Names.	Weight of a cubic foot.	Cost of working Fir being = 1.	Remarks.
		lbs.		
Assegai wood, or Cape Lancewood (*Curtisia faginea*)	Oomhlebe .	56	1·5	Colour, light red; grain like lancewood, very tough and elastic, used for wheel spokes, shafts, waggon rails, shafts of assegais, for turners' work, &c.
Cedar Boom (*Widdringtonia Junipernoides*)	.. ..	41	1·25	A kind of cypress, grows principally on the Cedar Mountains division of Clanwilliam, N. and W. of Cape Colony; used for floors, roofs, and other building purposes; grain not unlike Havannah cedar, but of a lighter colour; will not stand exposure to the weather.
Castanie, or Wild Chestnut (*Calodendron capense*)	.. ..	..	..	Timber very inferior, and warps much in seasoning.

* By Henry Hall, Esq., F.R.G.S., Surveyor in the Royal Engineer Department, and who for many years was professionally employed in South Africa.

TABLE—*continued.*

Common and Botanical Names.	Native Names.	Weight of a cubic foot.	Cost of working Fir being = 1.	Remarks.
		lbs.		
Doorn Boom, or Kameel Doorn (*Acacia giraffe, A. horrida*)	Mokohala Motootla	40	1·25	Several varieties of this species afford small timber available for fencing, spars, &c., and is also much used for fuel, charcoal, &c. Bark employed in tanning, otherwise of little value: there are several varieties affording gum.
Cape Ebony (*Euclea pseudo-baenus*, or *E. lanceolata*)	Itoomganzi Oomgwali Guarri	60	..	Not of any commercial value.
White Els, or Alder (*Weinmannia*, or *Platylophus trifoliatus*	.. ..	38	1·25	Used for paling, posts, and ordinary carpenters' work.
Red Els (*Cunonia capensis*)	.. ..	47	1·60	Grain the colour of red birch; is used for waggon building and farm purposes.
Rock Els (*Plectonia mundtiana*)	.. ..	..		A harder and smaller variety of the last.
Essen Hout, or Cape Ash (*Ekebergia capensis*)	Oomnyamati	48	1·40	Used for common floors, palings, &c.; is a tough and valuable timber, somewhat resembling elm: can be procured up to 18 inches square.
Flat Crownwood	.. ..	..	1 30	Grows in Natal to 2 feet diameter. The wood is similar to elm, but of a bright yellow colour, with a fine and even grain: used for the naves of wheels.
Iron wood, black (*Olea laurifolia*, or *Milletia Caffra*)	Tambooti, or Hooshe	64	2·00	Very heavy; the grain fine, like pear-tree; used for waggon axles, cogs for machine wheels, spokes, telegraph poles, railway sleepers, piles, &c.: is very durable, and can be obtained in logs up to 18 inches square.
Ditto, white (*Vepris lanceolata*)	Oomzimbiti	..	..	Used for the same purposes as the black variety.
Kafir Boom (*Erythrina Caffra*)	Oomsinsi, or Limsootsi	38	..	Wood, soft and light; the grain open and porous; splits easily; and is used principally for roof shingles, owing to its not being liable to take fire.
Melk Hout, or Milk wood (*Sideroxylon inerme*) (*Mimusops Obovata*)	Oomtombi..	52	1·75	Colour, white: used in the construction of waggons (wheelwork). There is also a darker variety.

TABLE—*continued*

Common and Botanical Names.	Native Names.	Weight of a cubic foot.	Cost of working Fir being = 1.	Remarks.
		lbs.		
Red Mangrove (*Rhizophora Natalensis*)	.. ..	..	..	Used in Natal for posts and for fencing generally
Oliven Hout, or Wild Olive (*Olea verrucosa*)	Konka ..	60	2·00	This wood is of small size, and generally decayed at the heart: used for fancy turnery, furniture, &c.
Pear Hout (*Olinia capensis*)	Kwa . ..	46	..	Resembles European pear-tree; but is closer in the grain.
Saffraan Hout (*Ilex crocea*)	.. ..	54	..	A kind of evergreen oak; used for farm purposes. The wood is strong and tough; the bark is used for tanning.
Nies Hout, or Sneezewood (*Pteroxylon utile*)	Oomtata ..	68	3·00	A most durable and useful timber, resembling satinwood; very full of a gum or resin resembling guaiacum; burns like candlewood; invaluable for railway sleepers, piles, &c., as it is almost imperishable, and is very useful for door and sash sills or similar work. It is difficult to be procured of large scantling.
Stinkwood (*Laurus bullata*, or *L. Orcodaphne*)	.. ..	53	1·6	Resembles dark walnut in grain; is used for furniture, gun-stocks, &c.; while working, it has a peculiar odour; stands well when seasoned; usually to be obtained in planks from 10 to 16 inches wide and 4 inches thick; there are one or two varieties, which are inferior.
Geel Hout, or Yellow wood (*Taxus elongatus*, or *Podocarpus Thunbergii*)	Oomkoba ..	40	1·35	This, which is of the Yew-tree genus, is one of the largest trees that grows in the Cape, and is often found upwards of 6 feet in diameter. The wood is extensively used for common building purposes; it warps much in seasoning, and will not stand exposure to the weather; the colour is a light yellow, which, with the grain, resembles lancewood; it shrinks in length about $\frac{1}{80}$th part. There is another variety called "Bastard Yellow-wood," that grows along the banks of rivers, which is inferior to the other.
Wilge Boom, or Willow (*Salix gariepina*)	.. ..	38	..	This wood, which grows along the banks of rivers, is of little value, as it is soon destroyed by worms; but is used where other timber is scarce. It, however, makes good charcoal.

619. Besides the timber trees given in the foregoing Table, there are several varieties of smaller size, such as the Tambooti, Sandal, Ebony, Bastard Ebony, and Lignum Vitæ, found in the forests of Kaffraria, Natal, and the Zambesi region. They are generally very heavy and of close grain; used by the natives for manufacturing clubs, weapons of war, domestic utensils, &c., but at present of little value for building purposes.*

BRITISH GUIANA.

620. GREENHEART (*Nectandra rodiœi*), called by the natives "Sipiru," is very abundant within 100 miles of the coast. Balks of the timber, squaring from 18 to 24 inches, may be had from 50 to 60 feet long without a knot.

The wood is hard and fine, but not even-grained. It is remarkable both for strength and durability. The colour of the sap-wood is a pale yellow, and the heart-wood a deep brown. It is said not to be liable to the attacks of the sea-worm. An instance is on record of a ship in the port of London having nearly the whole of the bottom planking eaten into by the worms with the exception of one plank, which proved to be of greenheart timber.† It was also found by Mr. Stevenson, at the Bell Rock, to resist the attacks of the *Limnoria terebrans* better than any other wood.

In consequence of this valuable property, greenheart timber in its natural state is almost the only wood now in use for harbour works that is proof against the attacks of the *Teredo navalis* or the *Limnoria terebrans*, and it ranks next to teak in tropical countries for resisting the white ant. This immunity is supposed to be from its possessing a large quantity of some powerful empyreumatic oil.

Greenheart is therefore well adapted for planking vessels,

* See 'Report of the Colonial Botanist to the Cape Parliament in 1866,' in which a list of 460 shrubs and forest trees is given.

† 'Min. Proc. Inst. of Civil Engineers,' 1852–3.

wharves, bridge piles, and all structures under water. Great care, however, is required in working it, from its liability to split. In sawing, the log requires to be tightly bound with chains to prevent its breaking up in splinters, which would be very apt to injure the men who were working it. It is imported into this country chiefly from Demerara, and has been largely used at Liverpool and other places in the north of England and Scotland. The weight of a cubic foot varies from 58 to 65 lbs. The crushing force in the direction of the fibre of a piece 1 inch square and 1 inch high is about 12,000 lbs.;* and the transverse strength of a specimen 1 foot long, between the supports, and 1 inch square, when loaded in the middle, is 1434 lbs.

There is another variety of greenheart, the wood of which is heavier and the colour darker. It is also more durable, but not as plentiful.

621. Mora (*Mora excelsa*).—This is one of the most majestic trees of the forests of Guiana, where it attains a height of from 100 to 150 feet, and is frequently found 60 feet in height without a branch. When of that length it will square 18 or 20 inches, but is then seldom sound throughout. The wood is extremely tough, close, and cross-grained, so that it is difficult to split, which renders it peculiarly adapted for ship-building. The trunk makes admirable keels, timbers, and beams, and the branches, having a natural crookedness of growth, are unsurpassed as knees. Were men-of-war ceiled with this wood, little mischief would be occasioned by splinters during action. In most respects it is superior to oak, particularly in its exemption from dry rot. This, as well as greenheart, ranks as one of the eight first-class woods at Lloyd's for ship-building. It is abundant along the rivers

* A cylindrical pillar $8\frac{1}{3}$ feet long and 5·644 inches diameter, tested by Kirkaldy, required $120\frac{1}{3}$ tons to crush it, or about 10,785 lbs. on the square inch.

of the coast region: it grows luxuriantly on sand reefs and on tracts of barren clay known as "Mora clay." The bark of the Mora is used for tanning.

The weight of a cubic foot, when dry, is about 57 lbs.; the crushing force of a column 1 inch square and 1 inch high, is about 10,000 lbs.; and the transverse strength of a specimen 1 foot long between the supports and 1 inch square, is, when loaded in the middle, about 1212 lbs.*

West India Islands.

622. Cedar (*Cedrela odorata*).—This tree is to be found chiefly in Cuba, Jamaica, and Honduras, growing with a stem of 70 or 80 feet in height, and with a diameter of 3 to 5 feet. It is known to cabinet-makers as the Havannah or West Indian Cedar, and is exported in logs sometimes of 3 to 4 feet square. The wood is of a red colour, resembling the pencil cedar (*Juniperus*); it is soft, porous, and brittle, and used chiefly for the inside of furniture. The cigar-boxes from Havannah are made of it.

It affords most durable planks and shingles. Another variety of the same species is chiefly obtained from Andros Island, but used throughout the Bahama Islands for frames, posts, and girders in house-building. The wood is soft, fine, close-grained, and rather light, possessing the pink hue and emitting the odour of the common pencil cedar. When fully grown the tree is from 16 to 20 feet long, and 1 foot in diameter, and is generally cut into 10 to 16 feet lengths, from 5 to 8 inches square.

Another kind, the wood of which has a curled and shaded appearance, obtained by its growth on a rocky soil, is used for picture-frames and cabinet work.

The weight of a cubic foot of the *Cedrela odorata* of Jamaica and Cuba is about 36 lbs. The crushing strength per

* 'Report on the Paris Exhibition.'

square inch in the direction of the fibre is about 6600 lbs., and the transverse strength of a specimen 1 foot long between the supports, and 1 inch square, loaded in the middle, is about 399 lbs.

623. LIGNUM VITÆ (*Guaiacum officinale*).—It is from this tree, which grows chiefly on the south side of the island of Jamaica, that the well-known wood used in the sheaves of blocks and pulleys is obtained, and also the medicinal gum resin known as guaiacum. Lignum vitæ is one of the hardest, heaviest, and most useful kinds of wood. It is calculated to endure a vast amount of friction, and to bear the strain of enormous weights. The colour of the heart-wood is a very dark brown, and the sap-wood a light yellow. When the wood is used for the sheaves of blocks, it should be cut so that a band of the sap may be preserved all round, as this preserves the sheaves from splitting from the outside inwardly towards the centre.

The wood is very liable to split and crack in drying.

The weight of a cubic foot is 73 lbs., and the crushing force of a cubic inch in the direction of the fibre is about 9900 lbs.

624. BROADLEAF (*Terminalia latifolia*).—This tree, which is sometimes called the "Almond tree," from the shape of its fruit, grows in Jamaica to a considerable height, often to 60 feet before reaching the main branches, and with a diameter of from 3½ to 5 feet. It is used for timbers, boards, shingles, and staves.

The weight of a cubic foot when dry is 48 lbs. The crushing force of a short prism 1 inch square is about 7500 lbs. The transverse strength of a specimen 1 foot long between the supports, and 1 inch square, when loaded in the middle, is about 750 lbs.

625. THE BULLET TREE (*Achras sideroxylon*).—The wood of this tree is very hard and durable, and fitted for most kinds of outside work. It is used principally for posts and

sills of framing and also for rafters. It warps a good deal in seasoning, and splits easily in the direction of the fibres; if used in floors it becomes slippery after a time. It is very liable to the attack of the sea-worm. The bullet-tree is obtainable in large sizes, and is considered one of the best timber trees in the West Indies.

The weight of a cubic foot when dry is about 65½ lbs., and the crushing force of a prism 1 inch square is 14,330 lbs.

626. Locust (*Hymenœa Courbaril*).—This tree, though growing plentifully on the plains and mountains in parts of Jamaica, is said not to be a native of that island. It is, however, a useful timber for house-building, being hard and tough. The gum animi used in varnishing is produced by the roots of this tree.

The weight of a cubic foot, when dry, is 42 lbs. The crushing force of a short prism 1 inch square is about 7500 lbs.; and the transverse strength of a specimen 1 foot long between the supports and 1 inch square is 750 lbs.

Books referred to in compiling the foregoing Articles on Timber.—'Vitruvius;' Evelyn's 'Silva;' Duhamel, 'Transport des Bois;' Pursh's 'N. American Flora;' Miller's 'Gardener's Dictionary;' Ellis's 'Timber Tree Improved;' Rees's 'Cyclopædia;' Lambert's 'Travels in Canada;' Michaux's 'Travels;' and 'North American Sylva;' Oliver's 'Travels;' Belidor, 'Science des Ingénieurs;' Barlow's 'Essay on the Strength of Timber;' Rondelet, 'L'Art de Bâtir;' Winch, 'On the Geography of Plants;' Knowle's 'Inquiry concerning the Navy;' Morgan and Creuze's 'Papers on Naval Architecture;' Von Buch's 'Travels in Norway;' Linnæus's 'Tour in Lapland;' Coxe's 'Travel's in Norway;' Thunberg's 'Travels;' Chapman, 'On the Preservation of Timber;' Matthews, 'On Naval Timber;' Fincham's 'Outline of Ship-building'; Rhind's 'Hist. of the Vegetable Kingdom;' Loudon's 'Ency. of Trees and Plants;' Balfour's 'Class Book of Botany;' Selby's 'Hist. of British Forest Trees;' Brown's 'Forester;' 'Report on the Paris Exhibition;' 'Dict. of the Arch. Publication Society;' Spons' 'Information for Colonial Engineers,' edited by J. T. Hurst;' Laslett's 'Timber and Timber Trees;' W. N. Blair's 'Building Materials of Otago.'

APPENDIX TO ARTS. 478 AND 479

In 1879 the Editor examined some fender piles of fir which were being removed from the Clarence Esplanade Pier at Southsea, in consequence of the ravages of the *Limnoria terebrans.* These piles had been in their place about ten years, and were thoroughly creosoted, the odour of which was still quite strong in the untouched portions. A few *Chelura terebrans* were also found in the wood.

On the opposite side of Spithead, in a temporary landing stage used for the erection of St. Helen's Fort, at the mouth of Brading Harbour, were some fir piles 13 inches square, which had been fixed about fifteen years, and creosoted with from 4 to 6 lbs. of the oil per cubic foot. These had been eaten completely through by the Chelura.

The Editor also discovered *Tanais vittatus* in beech piles used for the groynes in front of Southsea Castle. This species belongs to the same family as the Limnoria, but it had been hitherto unknown to naturalists as a wood borer.

The *Limnoria* and *Chelura terebrans* do not attack wood more than a few inches above high-water of neap tides; below this level there is scarcely a piece of wood in Portsmouth Harbour or along the coast which has been submerged more than two or three years that is not attacked by these minute crustacea. Unprotected timber will be completely destroyed in less than ten years, but creosoted timber appears to require fifteen years.

The Limnoria will exist in comparatively foul water if salt, but the Chelura must have sea-water comparatively pure, hence the former is most frequently found in harbours, and the latter along the sea-coast. To preserve piers and staging from these animals, iron should always be used below high water of neap tides. This has been adopted by Captain Carey, R.E., in his design for the permanent landing stage of St. Helen's Fort.

TABLES.

No. I.

Table of the Scantlings of Girders of Baltic Pine,* for Different Bearings, from 10 to 36 feet; Girders 10 feet apart from middle to middle. See Sect. III., Arts. 196 to 208.

Length of bearing in feet.	Depth 10 in.	Depth 11 in.	Depth 12 in.	Depth 13 in.	Depth 14 in.	Depth 15 in.	Depth 16 in.	Depth 17 in.	Depth 18 in.
	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.
10	7½	5½	4	3½	2¾	2¼	1¾	1½	1¼
11	9	6¾	5	4¼	3¼	2¾	2¼	2	1¾
12	10½	8	5¾	5	3¾	3¼	2¾	2¼	2
13	12½	9½	6¾	5¾	4½	3¾	3	2½	2¼
14	14½	10¾	7¾	6¾	5¼	4½	3½	3	2½
15	16½	12½	9	7¾	6	5	4	3½	3
16	18¾	14	10¼	8¾	7	5¾	4¾	4	3¼
17		16	11½	9¾	8	6¼	5¼	4½	3¾
18	..	17¾	13	11	8¾	7¼	6	5	4
19	..	19¾	14½	12	9¾	8	6½	5½	4¾
20	..		16	13½	10¾	9	7¼	6	5¼
21	..	..	17½	15	12	9¾	8	6¾	5¾
22	..	..	19½	16½	13	10¾	8¾	7½	6¼
23	..	..		18	14¼	11½	9½	8	6¾
24	..	..	..	19½	15½	12¾	10½	8¾	7½
25					16¾	13¾	11¼	9½	8
26	Depth 19 in.	Depth 20 in.	Depth 21 in.		18¼	15	12¼	10¼	8½
27					19¾	16	13	11	9¼
28	Breadth, inches.	Breadth, inches.	Breadth, inches.			17¼	14¼	11¾	10
29						18½	15¼	12¾	10¾
30	9¾	8½	7¼			19¾	16¼	13½	11½
31	10¼	9	7¾				17¼	14½	12¼
32	11	9½	8¼				18½	15½	13
33	11¾	10	8¾				19¾	16½	14
34	12½	10¾	9½					17½	14¾
35	13¼	11½	10					18½	15¾
36	14	12	10½					19½	16½

Example.—The scantling for a girder of 20 feet bearing may be 16 inches in breadth and 12 inches deep; or the breadth may be 13½ inches, and the depth 13 inches, and so on; but where there is space to admit of a deep girder it requires less timber.

This Table is calculated by the equation $\frac{74\,l^2}{d^3} = b$; where l is the length in feet, and b and d the breadth and depth in inches. The bearing is the distance between the centres of the supporting wall-plates; and the scantlings the least that will answer the purpose.

* *Pinus sylvestris*, see Art. 515.

No. II.

Table of the Scantlings of Binding Joists, of Baltic Pine, for Different Bearings, from 5 to 20 feet, when the distance from middle to middle is 6 feet. See Sect. III., Arts. 209 and 210.

Length of bearing in feet.	Depth 6 in.	Depth 7 in.	Depth 8 in.	Depth 9 in.	Depth 10 in.	Depth 11 in.	Depth 12 in.	Length of bearing in feet.
	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	breadth, inches.	
5	4¾	3	2					5
6	6¾	4	3	2				6
7	——	5½	4	2¾	2			7
8	..	7	5¼	3¾	2¾	2		8
9	..	——	6½	4½	3½	2½		9
10	..	..	8	5½	4	3	2½	10
11	Depth 13 in.	Depth 14 in.	Depth 15 in.	6¾	5	3¾	3	11
12				8	6	4½	3½	12
13	Breadth, inches.	Breadth, inches.	Breadth, inches.	——	7	5¼	4	13
14					8	5¾	4½	14
15	4	3½	2¾		9	6¾	5¼	15
16	4½	3¾	3¼		10¼	7¾	6	16
17	5¼	4¼	3½		——	8¾	6¾	17
18	5¾	4¾	4			10	7½	18
19	6½	5½	4¼			——	8½	19
20	7¼	6	4¾				9½	20

Example.—If it be required to find the scantling for a binding joist for a 10 feet bearing, assume 9 inches to be the depth suited to the floor; then, opposite 10 feet, in one of the side columns, and under 9 inches at the head of one of the middle columns, we find 5½ inches, the breadth required. If 8 inches had been fixed upon for the depth, it would have required 8 inches in breadth to be equally as stiff as one 9 by 5½. If the bearing be 19 feet, and 13 inches should be of convenient depth, then opposite 19 in the side columns, and under depth 13 inches, we find 6½ inches, the breadth required.

This Table is calculated by the rule $\frac{40\,l^2}{d^3} = b$; where l is the length in feet; and d the depth, and b the breadth, each in inches.

No. III.

TABLE of the SCANTLINGS for SINGLE JOISTING, or BRIDGING JOISTS, of BALTIC PINE, for DIFFERENT BEARINGS, from 5 to 25 feet; the distance middle to middle, 12 inches. See Sect. III., Arts. 195 and 213.

Length of bearing in feet.	Breadth, 1½ in.	Breadth, 1¾ in.	Breadth, 2 in.	Breadth 2¼ in.	Breadth, 2½ in.	Breadth, 2¾ in.	Breadth, 3 in.	Breadth, 3¼ in.	Breadth, 3½ in.	Breadth, 4 in.
	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.
5	5¾	5½	5¼	5	4¾	4½	4⅜	4¼	4⅛	4
6	6¼	6	5¾	5½	5⅜	5¼	5	4⅞	4¾	4½
7	7	6¾	6½	6¼	6	5¾	5½	5¾	5¼	5
8	7¾	7½	7	6¾	6½	6⅜	6¼	6	5⅞	5¾
9	8½	7⅞	7½	7	6⅞	6¾	6½	6¼	6	5⅞
10	9	8½	8	7¾	7½	7¼	7	6⅞	6¾	6½
11	9½	9	8¾	8½	8	7¾	7½	7¼	7	6¾
12	10	9¾	9½	9	8½	8¼	8	7¾	7½	7¼
13	10¾	10¼	9¾	9½	9	8¾	8½	8¼	8	7¾
14	11	10½	10	9¾	9½	9¼	9	8¾	8½	8
15	11½	11	10½	10	9¾	9½	9¼	9	8¾	8½
16	12¼	11½	11	10¾	10½	10	9¾	9½	9¼	8⅞
17	12¾	12	11½	11¼	10¾	10½	10¼	10	9¾	9¼
18	13¼	12½	12	11½	11¼	10¾	10½	10¼	10	9½
19	13¾	13	12½	12	11½	11¼	10¾	10½	10¼	10
20	14¼	13½	13	12½	12	11½	11¼	11	10¾	10¼
21	14¾	14	13½	12¾	12½	12	11¾	11½	11	10¾
22	15	14½	13¾	13¼	12¾	12½	12	11¾	11½	11
23	15½	14¾	14	13½	13	12¾	12¼	12	11¾	11¼
24	16	15¼	14½	14	13½	13¼	12¾	12½	12	11¾
25	16½	15½	15	14½	14	13½	13	12¾	12½	12

Example.—For a 14 feet bearing, a joist 10 by 2 is of the same degree of stiffness as one 9 by 3, or as one of any other depth opposite 14, with the breadth at the top of the column.

This Table was calculated by the equation $\left(\frac{l^2}{b}\right)^{\frac{1}{3}} \times 2 \cdot 2 = d$. See Art. 195.

No. IV.

Table of the **Scantlings** of **Ceiling Joists**, of **Baltic Pine**, for **Different Bearings**, from 4 to 15 feet; distance from middle to middle, 12 inches. See Sect. III., Art. 214.

Length of bearing in feet.	Breadth, 1¼ in.	Breadth, 1½ in.	Breadth, 2 in.	Breadth, 2¼ in.	Breadth, 2½ in.	Breadth, 2¾ in.	Breadth, 3 in.
	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.
4	2¼	2⅛	2	..	..	..	..
5	2¾	2⅝	2½	..	..	..	..
6	3⅜	3¼	3	2⅞	..	..	..
7	4	3¾	3½	3⅜	3¼	..	..
8	4½	4¼	4	3⅞	3¾	3⅝	3½
9	5	4¾	4½	4⅜	4¼	4⅛	4
10	5¾	5⅜	5	4⅞	4¾	4⅝	4½
11	6¼	5⅞	5½	5⅜	5¼	5⅛	5
12	6¾	6½	6	5⅞	5¾	5⅜	5¼
13	7½	7	6½	6¼	6	5⅞	5¾
14	8	7½	7	6¾	6½	6⅜	6¼
15	8½	7⅞	7½	7⅜	7¼	7	6¾

Ceiling joists should never have very long bearings, particularly those for ceilings next the roof of a house; as long joists are subject to warp, which breaks the plastering.

The distance from middle to middle should never exceed 12 inches, otherwise the bearing for the laths becomes too long. If the distance from middle to middle exceeds 12 inches, double laths should be used.

This Table is calculated by the rule $\frac{\cdot 64\, l}{b^{\frac{1}{3}}} = d$; where l is the length, d is the depth, and b the breadth.

No. V.

TABLE of SCANTLINGS of TIMBER for DIFFERENT SPANS, from 20 to 30 feet, for the ROOF shown in PLATE I. See Sect. IV., Art. 229.

Span.	Tie-beam A.	King-post K.	Principal rafters P.	Braces B.	Purlins C.	Small rafters *r*.
feet.	inches.	inches.	inches.	inches.	inches.	inches.
20	9½ × 4	4 × 3	4 × 4	3½ × 2	8 × 4¾	3½ × 2
22	9½ × 5	5 × 3	5 × 3	3¾ × 2¼	8¼ × 5	3¾ × 2
24	10½ × 5	5 × 3½	5 × 3½	4 × 2½	8½ × 5	4 × 2
26	11½ × 5	5 × 4	5 × 4¼	4¼ × 2½	8¾ × 5	4¼ × 2
28	11½ × 6	6 × 4	6 × 3½	4½ × 2¾	8¾ × 5¼	4½ × 2
30	12½ × 6	6 × 4½	6 × 4	4¾ × 3	9 × 5½	4¾ × 2

In this Table the trusses are supposed to be not more than 10 feet apart, the pitch of the roof about 27 degrees, the covering slate, and the timber Baltic pine. The timbers are marked with the letters A, K, P, B, C, and *r*, in the engraving.

No. VI.

TABLE of SCANTLINGS for ROOFS, from 30 to 46 feet SPAN, DESIGN, PLATE II.; TRUSSES 10 feet apart. See Sect. IV Art. 230.

Span.	Tie-beam A.	Queen-posts Q.	Principal rafters P.	Straining beam S.	Braces B.	Purlins C.	Small rafters *r*.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
32	10 × 4½	4½ × 4	5 × 4½	6¾ × 4½	3¾ × 2¼	8 × 4¾	3½ × 2
34	10 × 5	5 × 3½	5 × 5	6¾ × 5	4 × 2½	8¼ × 5	3¾ × 2
36	10½ × 5	5 × 4	5 × 5¾	7 × 5	4¼ × 2½	8¼ × 5	4 × 2
38	10 × 6	6 × 3¾	6 × 6	7¼ × 6	4½ × 2½	8½ × 5	4 × 2
40	11 × 6	6 × 4	6 × 6	8 × 6	4½ × 2½	8¾ × 5	4¼ × 2
42	11½ × 6	6 × 4½	6¼ × 6	8¼ × 6	4½ × 2¾	8¾ × 5¼	4½ × 2
44	12 × 6	6 × 5	6½ × 6	8½ × 6	4½ × 3	9 × 5	4¾ × 2
46	12½ × 6	6 × 5½	7 × 6	9 × 6	4¾ × 3	9 × 5½	5 × 2

Pitch of the roof about 27 degrees, covering slate, and timber Baltic pine. The letters refer to the engraving, as in the Table above.

The scantlings in these Tables are calculated by the rules in Sect. IV. The smallest scantlings have been taken that ought to be used for good Riga or Memel timber; soft and inferior kinds of timber will require them to be larger.

No. VII.

Table of Scantlings for Roofs of from 46 to 60 feet Span, to Design, Plate III.; Trusses 10 feet apart. See Sect. IV., Art. 231.

Span.	Tie-beam A.	Queen-posts Q.	Posts D.	Principal rafters P	Straining beam S.	Braces B.	Purlins C.	Small rafters r.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
48	11½×6	6 ×5¾	6×2¼	7½×6	8¼×6	4½×2¾	8½×5	4 ×2
50	12 ×6	6 ×6¼	6×2½	8½×6	8½×6	4½×2¾	8¾×5	4¼×2
52	12 ×6½	6 ×6¾	6×2¾	9¼×6	8¾×6	4¾×2¾	8¾×5¼	4¼×2
54	12 ×7	7 ×6¼	7×2¼	8¼×7	9 ×6	4¾×2¾	8¾×5¼	4½×2
56	12 ×8	7 ×6¾	7×2½	8½×7	9¼×6	5 ×2¾	8¾×5¼	4½×2
58	12 ×8½	7 ×7¼	7×2¾	8¾×7	9½×7	5 ×2¾	9 ×5¼	4¾×2
60	12 ×9	7½×7	7×3	9 ×7	10 ×7	5 ×3	9 ×5½	4¾×2

No. VIII.

Table of Scantlings for Roofs, from 60 to 90 feet Span, to Design, Plate IV.; Trusses 10 feet apart. See Sect. IV., Arts. 232 and 233.

Span.	Tie-beam A.	Queen-posts Q.	Posts D, D.	Principal rafters P.	Straining beam S.	King-post K.	Braces B.	Purlins C.	Small rafters r.
feet.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
65	15×10½	8 ×7	5×3	8 × 7½	10½× 8	5×3	5×3½	8¼×5	4 ×2
70	15×11¾	9 ×6½	5×3½	9 × 7	10½× 9	5×3½	5×3¼	8½×5	4¼×2
75	15×13¾	9 ×7½	5×4	9 × 8	11¼× 9	5×4	5×4½	8¾×5	4½×2
80	16×13	9 ×9	6×4	10 × 9	12 × 9	6×4	6×3½	8¾×5¼	4½×2
85	16×13½	9½×9	6×4½	11. × 9	12¾× 9	6×4½	6×4	9 ×5¼	4¾×2
90	16×14	10 ×9¾	6×4½	11. ×10	13 ×10	6×4½	6×4	9 ×5½	5 ×2

In these Tables the pitch of the roof is supposed to be about 27 degrees, the covering slate, and the timber to be good Riga or Memel pine. Inferior timber will require to be of larger dimensions, but the addition of one-fourth of an inch to each dimension will be sufficient for any difference in quality, except it be knotty timber. The letters refer to the parts on the engravings.

No. IX.

Table of Scantlings for Roofs, from 55 to 65 feet Span, to Design, Plate V.; Trusses 10 feet apart. See Sect. IV., Art. 234.

Span.	Tie-beam A.	Queen-posts Q.	Principal rafters P.	Straining beam S.	Posts D.	Braces B.
feet.	inches.	inches.	inches.	inches.	inches.	inches.
55	12 × 8	8 × 6	8 × 8	10 × 8	6 × 4	6 × 4
60	12 × 9	9 × 6	9 × 7	10 × 9	6 × 4½	6 × 4½
65	13 × 9½	9½ × 6½	9½ × 8	11 × 9½	6 × 5	6 × 5

In roofs of this design, and between 55 and 65 feet span, the purlins may be 9 inches by 5 inches, and common rafters 5 inches by 2 inches.

No. X.

Table of Scantlings for Roofs, from 70 to 80 feet Span, to Design, Plate VI.; Trusses 10 feet apart. See Sect. IV., Art. 235.

Span.	Tie-beam A.	Queen-posts Q.	Principal rafters P.	Straining beam S.	
feet.	inches.	inches.	inches.	inches.	
70	15 × 11½	9½ × 8	13 × 9½	12 × 9½	Scantlings of the upper parts may be obtained from Table No. V.
75	15 × 14	10 × 8½	13½ × 10	12 × 10	
80	16 × 13	10½ × 9	14 × 10½	13 × 10½	
85	16 × 14½	11 × 10	14½ × 11	13 × 11	

No. XI.

Table of Scantlings for Roofs, from 20 to 32 feet Span, to Design, Plate VIII.; Trusses 10 feet apart. See Sect. IV., Art. 237.

Span.	Tie-beam.	Curved rib.	Suspending Pieces.		Purlins.	Common rafters.
			No. of Pairs.	Scantlings of each Piece.		
feet.	inches.	inches.		inches.	inches.	inches.
20	8 × 4	4 × 4	3	4 × 2	8 × 5	3½ × 2
24	8 × 4	4¾ × 4	3	4 × 2	8 × 5	4 × 2
28	8 × 5	5¼ × 5	3	4 × 2¼	8½ × 5	4½ × 2
30	8½ × 5	6 × 5	3	4 × 2¼	8½ × 5	4¾ × 2
32	9 × 5½	6 × 5½	3	4 × 2½	8½ × 5	5 × 2

The pitch, &c., the same as in the preceding Tables.

No. XII.

TABLE of SCANTLINGS for ROOFS, from 35 to 100 feet SPAN, to DESIGN, FIG. 1, PLATE VII.; TRUSSES 10 feet apart. See Sect. IV., Art. 236.

Span.	Tie-beam.	Curved rib.	Suspending Pieces. No. of Pairs.	Suspending Pieces. Scantling of each Piece.	
feet.	inches.	inches.		inches.	
35	11 × 6	6 × 6	4	4 × 2½	Purlins, 9 × 5 inches. Small rafters, 5 × 2 inches.
40	11 × 6	7 × 6	4	4 × 2¾	
45	11 × 6½	8 × 6½	5	4 × 2¾	
50	11 × 7	9 × 7	5	4 × 3	
55	11 × 7	10 × 7	6	4 × 3	
60	11 × 8	10 × 8	6	4 × 3¼	
65	11 × 9	10 × 9	7	4 × 3¼	
70	11 × 9½	11 × 9½	7	4½ × 3¼	
75	11 × 10	11 × 10	8	4½ × 3¼	
80	12 × 10	12 × 10	9	4½ × 3¼	
85	12 × 11	12½ × 11	9	4½ × 3½	
90	12 × 11	14 × 11	10	5 × 3¼	
95	12 × 12	14 × 12	11	5 × 3½	
100	12 × 12	15 × 12	11	5 × 4	

The pitch is supposed to be about 27 degrees, the covering slate, and the timber good Riga or Memel pine.

No. XIII.

TABLE of the SCANTLINGS of BINDING JOISTS, of BALTIC PINE, that have to carry a CEILING only, for DIFFERENT BEARINGS, from 5 to 12 feet; distance apart not more than 6 feet. See Sect. III., Art. 212.

Length of bearing in feet.	Breadth, 2 in.	Breadth, 2½ in.	Breadth, 3 in.	Breadth, 3½ in.	Breadth, 4 in.	Breadth, 4½ in.	Breadth, 5 in.	Breadth, 5½ in.
	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.
5	4¾	4½	4¼	4	3¾	3½	..	..
6	5¾	5½	5	4¾	4½	4¼	..	..
7	6¾	6¼	6	5¾	5¼	5	..	..
8	7¾	7¼	6¾	6½	6	5¾	..	..
9	8¾	8	7½	7¼	6¾	6½	6¼	..
10	9¾	8⅞	8¼	8	7½	7¼	7	6¾
11	10½	9¾	9¼	8¾	8¼	8	7¾	7½
12	11½	10¾	10	9½	9¼	8¾	8½	8¼

No. XIV.

TABLE of the SCANTLINGS of PURLINS, of BALTIC PINE, for ROOFS for DIFFERENT BEARINGS, from 6 to 14 feet; distances apart 6 feet, 7 feet, 8 feet, 9 feet. See Sect. IV., Art. 264.

Length of bearing in feet.	6 feet apart.		7 feet apart.		8 feet apart.		9 feet apart.	
	depth, inches.	breadth, inches.	depth, inches.	breadth, inches.	depth, inches.	breadth, inches.	depth, inches.	breadth, inches.
6	6	3½	6¼	3¾	6½	4	6¾	4¼
7	6¾	4	7	4¼	7¼	4½	7½	4½
8	7½	4½	7¾	4¾	8	4¾	8¼	5
9	8¼	5	8½	5¼	8¾	5¼	9	5½
10	8¾	5¼	9¼	5½	9½	5¾	9¾	5¾
11	9½	5¾	9¾	5¾	10¼	6	10½	6¼
12	10	6	10½	6¼	10¾	6½	11¼	6¾
13	10¾	6½	11¼	6¾	11½	7	12	7¼
14	11¼	6¾	11¾	7	12¼	7¼	12½	7½

Purlins of less scantlings than in the Table may often appear strong enough, but in such cases the common rafters will be found to be stronger than is necessary. It is most economical to make the rafters no stronger than is necessary to carry the load between the purlins, and the purlins sufficiently strong to carry the rafters.

No. XV.

Table of the **Scantlings**, of **Common Rafters**, for **Roofs**, for **Different Bearings**, from 5 to 20 feet; distance apart 12 inches. See Sect. IV., Art. 265.

Length of bearing in feet.	Breadth, 1¾ in.	Breadth, 2 in.	Breadth, 2¼ in.	Breadth, 2½ in.	Breadth, 2¾ in.	Breadth, 3 in.	Breadth, 3½ in.	Breadth, 4 in.	Breadth, 4½ in.
	depth, inches.	depth, inches	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.	depth, inches.
5	3	2⅞	2¾	..	..	..	..	..	..
6	3¼	3½	3¼	3⅛	3	..	..	..	..
7	4⅛	4	3¾	3⅝	3½	..	..	..	..
8	4¾	4⅝	4⅜	4¼	4⅛	4	3¾	..	..
9	5¼	5⅜	5	4¾	4⅝	4½	4¼	..	..
10	6	5¾	5½	5⅜	5⅛	5	4¾	4½	..
11	6½	6¼	6	5¾	5⅝	5½	5¼	5	4¾
12	7	6¾	6½	6⅜	6¼	6	5¾	5½	5¼
13	7¾	7½	7¼	7	6¾	6½	6¼	5¾	5⅝
14	8¼	8	7¾	7½	7¼	7	6¾	6¼	6⅛
15	8¾	8½	8¼	8	7¾	7½	7¼	6¾	6⅝
16	9½	9¼	8¾	8½	8¼	8	7¾	7¼	7
17	10	9¾	9½	9	8¾	8½	8¼	8	7½
18	10½	10¼	10	9½	9¼	9	8¾	8½	8
19	11	10⅞	10½	10	9¾	9½	9	8¾	8¼
20	11¾	.11½	11	10½	10¼	10	9½	9	8¾

Roofs that are covered with plain tiles, or stone slate, will require rafters one-third stronger than is necessary for blue slate. The Table will answer for either, as it is calculated for blue slate; and if to the breadth found at the head of a column half of that breadth be added, it will give the breadth required for stone slate, or plain tiles. Thus, for a rafter of 7 feet bearing, 4 inches by 2 inches is sufficient for blue slate; and therefore 4 inches by 3 inches is the scantling for stone slate, or plain tiles.

Purlins also require the same addition to their breadths when the covering is of plain tiles, or stone slates.

No. XVI.

TABLE of the CRUSHING WEIGHT PER SUPERFICIAL INCH of SQUARE or RECTANGULAR P of ch the LENGTH does not exceed 30 times the LEAST THICKNESS. See Art. 160.

Kind of Wood.	Number of Times Length exceeds least Thickness.														
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Pine (Northern) ..	5192	4821	4552	4310	4032	3738	3441	3152	2879	2624	2390	2178	1986	1814	1659
Oak (English)	6234	5789	5466	5174	4841	4488	4132	3785	3456	3151	2870	2615	2385	2178	1992

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No. XVIII.

Table of the Properties of the Different Kinds of Timber used in England.

Kind of Wood.	Specific Grav.	Modulus of Elasticity in lbs. per square inch.	Cohesive Force in lbs. per square inch.	Comparative. Oak being = 100. Stiffness.	Strength.	Resilience.
Class I.—(Coniferous.)						
Riga pine (*P. sylvestris*) .. .. dry	·480	1,687,500	9,540	98	80	64
Memel pine „ .. .. „	·544	1,957,750	9,540	114	80	56
Mar Forest pine „	·684	845,066	7,323	49	61	76
Planted Scotch pine „ .. .. dry	·460	951,750	7,110	55	60	65
Weymouth pine (*P. strobus*) .. „	·460	1,633,500	11,835	95	99	103
Pitch pine (*P. rigida*)	·660	1,252,200	9,796	73	82	92
Christiana white deal (*A. excelsa*) dry	·512	1,804,000	12,346	104	104	104
Planted spruce „ .. „	·555	1,393,975	8,370	81	70	60
American white spruce (*A. alba*) „	·465	1,244,000	10,296	72	86	102
Larch (*L. Europa*) .. .. .. „	·643	1,363,500	12,240	79	103	134
Cedar of Libanus (*Cedrus libani*) „	·486	486,000	7,420	28	62	106
Cowrie (*D. Australis*) .. .. .. „	·579	1,982,400	10,960	116	92	74
Class II.—(Non-coniferous.)						
English oak (*Q. pedunculata*) .. dry	·750	1,714,500	11,880	100	100	100
Riga oak .. .. „	·688	1,610,496	12,888	93	108	125
Dantzic oak .. .. seasoned	·755	1,998,000	12,780	117	107	99
American oak (*Q. alba*)	·867	1,958,700	10,253	114	86	64
Beech (*F. sylvatica*) .. .. .. dry	·690	1,316,000	12,225	77	103	138
Alder (*A glutinosa*) .. .. .. „	·555	1,086,750	9,540	63	80	101
Plane (*P. occidentalis*) .. .. „	·648	1,343,250	10,935	78	92	108
Sycamore (*A. pseudo-platanus*).. „	·590	1,036,000	9,630	59	81	111
Chestnut (*F. castanea*) .. .. dry	·535	1,147,500	10,656	67	89	118
„ .. ..green	·875	924,750	8,100	54	68	85
Ash (*F. excelsior*) .. .. .. dry	·753	1,525,500	14,130	89	119	160
Elm (*U. campestris*) .. .. .. „	·544	1,343,000	9,720	78	82	86
Acacia (*R. pseudo-acacia*).. ..green	·820	1,687,500	11,227	98	95	92
Spanish mahogany (*S. mahogani*) dry	·853	1,255,500	7,560	73	67	61
Honduras „ „ „	·560	1,593,000	11,475	93	96	99
Walnut (*J. regia*) .. .. ..green	·920	837,000	8,775	49	74	111
Poplar (*P. dilatata*) .. .. .. dry	·374	763,000	5,928	44	50	57
Abele (*P. alba*) .. .. „	511	1,134,000	10,260	66	86	112
Teak (*T. grandis*)	·744	2,167,074	12,915	126	109	94
Poona (*C. Burmanni*) .. .. dry	·613	1,689,800	12,350	99	104	82
Turtosa .. .. „	·954	1,728,000	17,200	101	144	138

No. XIX.

Table of the Specific Gravity, Relative Strength, Flexibility, and Resilience of the Different Kinds of Timber used in Mast-making—(Fincham).

Species of Timber.		Specific Gravity. Green.	Specific Gravity. Dry.	Relative Strength.	Relative Deflection.	Relative Resilience or Toughness.
Riga pine	top	·682	·576	1000	1000	1000
	butt	·754	·656			
Red "	top	·647	·544	853	1500	980
	butt	·741	·638			
American spruce	top	·627	·541	764	1100	905
	butt	·678	·582			
Norway "	top	·595	·509	740	1260	860
	butt	·616	·520			
Adriatic "	top	·552	·467	709	864	872
	butt	·585	·493			
Yellow pine ..	top	·562	·430	746	1520	750
	butt	·665	·472			
Scotch spruce ..	top	·475	·389	476	1450	1100
	butt	·536	·440			
Cowrie	top	·604	·571	974	920	1086
	butt	·663	·619			
Poona	top	..	·632	1226	978	1146
	butt	..	·662			

No. XX.

Table of the Specific Gravity and Weight of Different Kinds of Wood.

Kind of Wood.	Specific Gravity.	Weight of a cub. ft. in lbs.	Kind of Wood.	Specific Gravity.	Weight of a cub. ft. in lbs.
Abele, dry	·511 F.	32·00	Chestnut (horse)	·657 H.	41·06
Acacia (false) green	·820 E.	51·25	,, ,, dry	·596 T.	37·28
,, dry	·791 H.	49·43	,, ,, another specimen, dry	·483 T.	30·18
,, dry	·748 T.	46·75	Cocoa wood	·1040 M.	65·00
,, (three thorned)	·676 H.	42·25	Cork	·240 M.	15·00
Alder	·800 M.	50·00	Cowrie	·579	36·20
,, dry	·555 E.	34·68	Crab-tree, meanly dry	·765 P.	47·81
Almond-tree	1·102 H.	68·87	Cypress	·655 H.	40·93
Apple-tree	·793 M.	49·56	,, (Spanish)	·644 M.	40·25
Apricot-tree	·789 H.	49·31	Deal, white. See Fir.		
Arbor vitæ (Chinese)	·560 H.	35·00	,, yellow. See Pine.		
Ash (heart-wood) dry	·845 P.	52·81	Ebony (American)	1·331 M.	83·18
,, dry	·832 W.	52·00	,, (Indian)	1·209 M.	75·56
,, young wood, dry	·811 T.	50·68	,,	1·108 R.	69·25
,,	·800 J.	50·00	Elder-tree	·695 M.	43·43
,,	·760 B.	47·50	Elm, green	·940 C.	58·75
,, (old tree) dry	·753 T.	47·06	,,	·693 S.	44·41
,, dry	·690 E.	43·12	,, seasoned	·588 C.	36·75
Bay-tree	·822 M.	51·37	,,	·553 B.	34·56
Beech, meanly dry	·854 P.	53·37	,, (common) dry	·544 E.	34·00
,,	·852 M.	53·25	,, wych, young tree, green	·763 E.	47·68
,,	·720 H.	45·00	Elm, ditto, dry	·684 T.	42·75
,,	·696 B.	43·50	Filbert-tree	·600 M.	37·50
,, dry	·690 E.	43·12	Fir (Norway spruce)	·512 T.	32·00
Birch, dry	·720 E.	45·00	,, (white American spruce)	·465 T.	29·06
Box (Dutch)	1·328 M.	83·00	Fir (silver) green	·531 Wi.	33·20
,, dry	1·030 J	64·37	,, dry	·403 Wi.	25·22
,,	1·031 P.	64·43	,, (Scotch). See Pine.		
,, from	1·024 B.	64·00	Fustic	·817 R.	51·06
,, to	·960 B.	60·00	Greenheart (yellow) from	·928	58·00
,, dry	·950 W.	59·37	Greenheart (yellow) to	1·040	65·00
,, (Turkey)	·949 R.	59·31	Hazel	·606 M.	37·87
Brazil wood (red)	1·031 M.	64·43	Hickory	·929 S.	58·06
Bullet-tree	1·048	65·50	Hornbeam	·760 H.	47·50
Canary wood	·723 R.	45·18	Iron bark	1·032	64·50
Cedar (Indian)	1·315 M.	82·18	Jarrah		
,, (Canadian)	·753 C.	47·06	Jasmine (Spanish)	·770 M.	48·12
,, (Virginian red) dry	·650 T.	40·62	Juniper wood	·556	34·75
,, (Palestine)	·596 M.	37·25	Laburnum	·843 T.	52·70
,, (American)	·560 M.	35·00	Lancewood	1·038 L.	64·87
,, ,, seasoned	·453 C.	28·31	,, dry	·943 R.	58·93
Cedar of Libanus	·603 H.	37·68	Larch, green	·858 Wi.	53·63
,, ,, dry	·486 T.	30·37	,, (red wood) seasoned	·640 T.	40·00
Cherry-tree	·741 H.	46·31	,, dry	·612 Wi.	38·31
,, dry	·672 T.	42·00	,, dry	·496 T.	31·00
Chestnut (sweet) green	·875 E.	54·68	,, (white wood) seasoned	·364 T.	22·75
,,	·685 H.	42·81			
,, (sweet), dry	·606 T.	37·95			
,, another specimen, dry	·535 T.	33·45			

No. XX.—*continued.*

Kind of Wood.	Specific Gravity.	Weight of a cub. ft. in lbs.
Lemon-tree	·703	43·93
Letter-wood	1·286 C.	80·37
Lignum vitæ	1·173 T.	73·31
"	1·327 P.	82·93
Lime-tree	·604 M.	37·75
"	·564 H.	35·25
"	·480 T.	30·00
Locust (Jamaica)	·672	42·00
Logwood	·913 P.	57·06
Mahogany (Spanish) dry	·852 T.	53·30
" dry	·816 W.	51·00
" (Honduras) dry	·560 T.	35·00
Maple (Norway)	·795 L.	49·68
" dry	·755 P.	47·18
" (common) dry	·624 T.	32·75
Medlar-tree	·944 M.	59·00
Moreton Bay pine, dry	·720	45·00
Mora, dry	·912	57·00
Mulberry-tree (Spanish)	·897 M.	56·06
Oak (live) half seasoned	1·216 Ch.	76·03
" (English) green	1·113 C.	69·56
" (French) green	1·063 Bu.	66·43
" (Irish bog)	1·046 C.	65·37
" (evergreen)	·994 H.	62·25
" (Adriatic)	·993 B.	62·06
" (black bog) dry	·965 R.	60·31
" (white American) half seasoned	·908 Ch.	56·75
Oak (*Q. sessiliflora*) dry	·879 T.	54·97
" (American) white	·840 H.	52·50
" (Provence) seasoned	·828 D.	51·75
" (*Q. pedunculata*) dry	·807 T.	50·47
" (English) seasoned	·777 C.	48·56
" (Dantzic) seasoned	·755 T.	47·24
" (American) red	·752 L.	47·00
" (Riga) dry	·688 T.	43·00
" (English) from an old tree, dry	·625 T.	39·06
Olive-tree	·927 M.	57·93
Orange-tree	·705 M.	44·06
Pear-tree, dry	·708 T.	44·25
"	6·6 B.	40·37
Pine (American pitch) dry	·936 T.	58·5
" (ditto) seasoned	·741 C.	46·31
" (pinaster) green	·837 Wi.	52·35
" (Scotch) green	·816 Wi.	51·08
Pine (Mar Forest)	·696 B.	43·50
" (planted Scotch) dry	·529 T.	33·06
" (Scotch) dry	·429 Wi.	26·81
" (Memel) dry from	·553	34·56
to	·544 T.	34·00
" (Riga) dry from	·480	30·00
to	·466 T.	29·12
" (Weymouth) dry	·460 T.	28·75
" (American Red) dry	·576	36·00
Plane (occidental) dry	·648 E.	40·50
" (oriental)	·538 H.	33·62
Plane-tree (common). See Sycamore.		
Plum-tree	·785 M.	49·06
"	·663 P.	41·43
Poon (seasoned)	·635 C.	39·95
Poplar (Spanish, white)	·529 M.	33·06
" (black) dry	·421 T.	26·31
" (Lombardy) dry	·374 E.	24·37
Quince-tree	·705 M.	44·06
Sassafras	·482 P.	30·12
Satinwood	·952 R.	59·50
Saul (Bengal) seasoned	·994 L.	62·12
Service-tree	·742 H.	46·37
Sissoo (Bengal) seasoned	·889 L.	55·52
Stinkwood (seasoned)	·681 C.	42·56
Stringy Bark	·864	54·00
Sycamore	·645 H.	40·31
" dry	·590 E.	36·87
Teak, dry	·832 Ch.	52·00
"	·745 B.	46·56
" seasoned	·657 C.	41·06
Tulip-tree	·477 H.	29·81
Vine	1·237 M.	77·31
Walnut-tree, green	·920 E.	57·50
" (American)	·735 H.	45·93
" (French)	·671 M.	41·93
" dry	·616 T.	38·50
Willow, green	·619 E.	38·68
" dry from	·568	35·50
to	·404 T.	25·25
Yellow wood, seasoned	·657 C.	41·06
Yew (Spanish)	·807 M.	50·43
" (Dutch)	·788 M.	49·25
"	·788 H.	48·62

The letters following the specific gravities refer to the authorities; B. Barlow; Bu. Buffon; C. Couch; Ch. from 'Chapman on Preservation of Timber'; E. Ebbels; H. from Rondelet's Table; J. Jurin; L. Layman; M. Muschenbroek; P. 'Philosophical Transactions,' vol. i., Lowthorp's Abridgment; R. Ralph Tredgold, who collected the information in this and the following Table; S. Scoresby; T. from the Author's own experiments; W. Watson (Bishop); and Wi. Wiebeking.

No. XXI.

Table of the Specific Gravity and Weight of Various Substances.

Name of Substance.		Specific Gravity.	Weight of a cub. ft. in lbs.
Air (atmospheric)		·0012	
Alabaster. See Gypsum.			
Asphalte (gritted)		2·496 Hu.	156·00
Basalt	from	3·00	187·50
	to	2·478	154·87
„ (Fairhead)		2·95 K.	184·37
„ (Derbyshire)		2·921 W.	182·56
„ (Giant's Causeway)		2·90 K.	181·25
„ „		2·864 Br.	179·00
„ (Rowley rag)		2·478 K.	154·87
Beeswax (yellow)		·965	60·31
Bismuth (cast)		9·822	613·87
Bitumen, of Judea		1·104	69·00
Brass (wire drawn)		8·544	534·00
„ (plate)		8·441 W.	527·56
„ (cast)		8·100 P.	506·25
Brick (common)	from	1·557	97·31
	to	2·000	125·00
„ (red)		2·168 Re.	135·50
„ (pale red)		2·085 Re.	130·31
„		1·857 Be.	116·06
„ (common London stock)		1·841 T.	115·06
Brick paving (English clinker)		1·653 R.	103·31
Brick (Dutch clinker)		1·482 R.	92·62
„ (Welsh fire)		2·408 T.	150·50
Brickwork in mortar, about		.. ..	110·00
Cement (Roman) and sand in equal parts		1·817 T.	113·56
Cement alone (cast)		1·600 R	100·00
Chalk	from	2·000 Hu.	125·00
	to	2·657 Th.	166·06
„ (Cambridge clunch)		2·657 W.	166·06
„ (Dorking)		1·869 R.	116·81
Charcoal from birch		·542 K.	33·87
„ from fir		·441 K.	27·56
„ from oak		·332 K.	20·75
„ from pine		·280 K.	17·50
Clay (potter's)	from	1·800	112·50
	to	2·085 K.	130·31
„ (common)		1·919 Be.	119·93
„ with gravel		2·560	160·00
„ slate. See Slate.			
Coal (Kilkenny)		1·526 K.	95·37
„ (Glasgow splint)		1·290 Th.	80·62
„ (Cannel)		1·272 Th.	79·50
„ (Newcastle caking)		1·269 Th.	79·31
Coke		·744 K.	46·50
Concrete (lime)		2·080	130·
„ (cement)		2·176	136·00
Copper (British sheet)		8·785 Ha.	549·06

Name of Substance.		Specific Gravity.	Weight of a cub. ft. in lbs.
Copper (British cast)		8·607 Ha.	537·93
Earth (common)	from	1·520	95·00
	to	1·984	124·00
„ (loamy or strong)		2·016	126·00
„ (rammed)		1·584	99·00
„ (loose or sandy)		1·520	95·00
Firestone		1·800	112·50
Flint	from	2·580	161·25
	to	2·630 Th.	164·37
„ (black Cambridge)		2·592 W.	162·00
Freestone. See Stone.			
Glass, white flint		3·000	187·50
„ plate		2·760	172·50
„ crown		2·520	157·50
Gold, pure cast		19·361 Br.	1210·06
„ standard		17·724 Th.	1107·75
Granite	from	2·999	187·47
	to	2·538 K.	158·62
„ (Guernsey)		2·960 Hu.	185·00
„ (Aberdeen grey)		2·664 R.	166·5
„ (Cornish)		2·662 Re.	166·37
„ (ditto)		2·653 R.	165·81
„ (Aberdeen red)		2·643 R.	165·18
„ (Cornish)		2·624 T.	164·00
Gravel		1·749 P.	109·32
Gunpowder (solid)		1·745	109·06
„ (shaken)		·922	57·62
Gutta-percha		·976 Hu.	61·00
Gypsum (plaster stone)		2·286 W.	142·87
India-rubber		·968 Hu.	60·50
„ (vulcanized)		1·040 Hu.	65·00
Iron (bar)	from	7·600	475·00
	to	7·800 K.	487·50
„ hammered		7·763 M.	485·18
„ not hammered		7·600 M.	475·00
„ (cast)	from	7·600	475·00
	to	7·200 Th.	450·00
„ horizontal ditto		7·113 Re.	444·56
„ vertical castings		7·074 Re.	442·12
Ivory		1·826 P.	114·12
Lead (milled)		11·407 Th.	712·93
„ (cast)		11·352 Br.	709·50
„ black. See Plumbago.			
Lime, quick		·843 Be.	52·68
Limestone. See Stone and Marble.			
Loam. See Earth.			
Marble	from	2·840	177·50
	to	2·580	161·25
„ Parian white		2·837 K.	177·31
„ veined white		2·726 Re	170·37

No. XXI.—*continued.*

Name of Substance.	Specific Gravity.	Weight of a cub. ft. in lbs.
Marble, Carrara white	2·717 K.	169·81
„ „ blue	2·713 K.	169·56
„ Italian black	2·712 K.	169·50
„ Derbyshire entrochal	2·709 R.	169·31
„ Saxon grey	2·700 K.	168·75
„ Brabant black	2·697 Re.	168·56
„ Derbyshire black	2·690 W.	168·12
„ Namur black	2·682 R.	167·62
„ Sienna yellow	2·677 K.	167·31
„ Pallion brown figured	2·586 R.	161·62
Marl — from	1·600	100·00
Marl — to	2·870 Th.	179·37
Mercury (fluid)	13·568 Br.	848·00
Mortar (new)	1·760 Hu.	110·00
„ of river sand 3 parts, of lime in paste 2 parts	1·615 Ro.	100·93
Mortar, ditto, ditto, well beat together	1·893 Ro.	118·31
Mortar, of pit sand 3 parts, of lime in paste 2 parts	1·588 Ro.	99·25
Mortar, ditto, ditto, well beat together	1·903 Ro.	118·93
Mortar, of pounded tile 3 parts, of quicklime 2 parts	1·457 Ro.	91·06
Mortar, ditto, ditto, well beat together	1·663 Ro.	103·93
Mortar, common, of chalk, lime, and sand, dry	1·550 R.	96·87
Mortar, the lining of an antique reservoir near Rome	1·549 Ro.	96·81
Mortar, from the interior of an old wall at Rome	1·414 Ro.	88·37
Mortar, lime, sand, and hair, used for plastering, dry	1·384 R.	86·50
Oolite. See Stone, Roe.		
Peat (hard)	1·329	83·06
Pebble (English)	2·609	163·06
Pewter	7·248	453·00
Pitch	1·150 P.	71·87
Plaster (cast)	1·286 Be.	80·37
Platina, pure	21·531 Th.	1345·68
Plumbago, or black-lead	2·267	141·68
Porphyry (green)	2·875	179·68
„ (red)	2·793	174·56
Potstone — from	3·000	187·50
Potstone — to	2·768 K.	173·00
Puzzolana — from	2·570	160·62
Puzzolana — to	2·850 K.	178·12
Quartz (crystallized)	2·655	165·93
Roe-stone. See Stone.		

Name of Substance.	Specific Gravity.	Weight of a cub. ft. in lbs.
Road grit. See Sand.		
Sand (pure quartz)	2·750	171·87
„ river	1·886 Be.	117·87
„ River Thames (best)	1·638 T.	102·37
„ pit (clean but coarse)	1·610 T.	100·62
„ „ (fine grained and clean	1·523 T.	95·18
Sand scraped from London roads (road grit)	1·494 T.	93·37
Sand, pit (very fine grained)	1·480 T.	92·50
„ River Thames (inferior)	1·454 T.	90·87
Sandstone. See Stone.		
Serpentine, Anglesey green	2·683 R.	167·68
„ blackish green	2·574 K.	160·87
„ dark reddish brown	2·561 K.	160·06
Silver, pure cast	10·474 Br.	654·62
„ standard	10·312 Th.	644·50
Slate, Welsh	2·888 K.	180·50
„ Anglesey	2·876 K.	179·75
„ Westmoreland pale blue	2·791 W.	174·43
Slate, ditto, dark blue	2·781 W.	173·81
„ ditto, pale greenish blue	2·768 W.	173·00
Slate, ditto, blackish blue, used for floors	2·758 W.	172·37
Slate, Welsh rag	2·752 K.	172·00
„ Westmoreland, fine grained, pale blue	2·732 W.	170·75
Slate, Cornwall, greyish blue	2·512 K.	157·00
Snow — from	·128 Hu.	8·00
Snow — to	·192 Hu.	14·00
Stone, Bath (roe-stone)	2·494 K.	155·87
„ „	1·975 R.	123·43
„ blue-lias (limestone)	2·467 R.	154·18
„ Bramley-fall sandstone	2·506 Re.	156·62
Stone „ „	2·261 R.	141·31
„ Bristol stone	2·510	156·87
„ Burford (dry piece)	2·049 P.	128·06
„ Caen (calcareous sandstone)	2·108 R.	131·75
Stone, Clitheroe limestone	2·686 W.	167·87
„ Collalo, white (sandstone)	2·423 Re.	151·43
Stone „ „	2·040 R.	127·50
„ Craigleith (sandstone)	2·452 Re.	153·25
„ „ „	2·360 R.	147·50
„ Derbyshire (red friable sandstone)	2·346 Re.	146·62
Stone, Dundee	2·530 Re.	158·12
„ „	2·517 T.	157·31

No. XXI.—*continued.*

Name of Substance.	Specific Gravity.	Weight of a cub. ft. in lbs.	Name of Substance.	Specific Gravity.	Weight of a cub. ft. in lbs.
Stone (grindstone)	2·143	133·93	Stone, Yorkshire paving ..	2·507 Re.	156·68
„ Hedding-stone, lax kind	2·029 P.	126·81	„ „ „ ..	2·356 R.	147·25
Stone, Hilton (sandstone)..	2·177 R.	136·06	Stonework, mean weight according to Belidor about	.. ..	107·00
„ Kentish rag	2·656 Hu	166·00			
„ Ketton (roe-stone) ..	2·494 K.	155·87	Shingle	1·520 Hu.	95·00
„ „	2·058 R.	128·62	Steel .. .. .. from	7·780	486·25
„ Kincardine (sandstone)	2·448 T.	153·00	to	7·840 Th.	490·00
„ Limerick (black compact limestone) .	2·598 Re.	162·37	Syenite (Mount Sorrel) ..	2·621	163·81
			Tile (common plain) ..	1·858 R.	116·15
Stone, Pennarth (limestone)	2·653 W.	165·81	„ „ „ ..	1·815 Be.	113·43
„ Portland (roe-stone).	2·461 W.	153·81	Tin, hammered	7·299 Br.	456·18
„ „ „ ..	2·423 Re.	151·43	„ pure cast	7·291 Br.	455·68
„ „ „ ..	2·113 R.	132·06	Toadstone (Derbyshire) ..	2·921 W.	182·56
„ pumice	·629 R.	39·31	Tufa (Roman)	1·217 Ro.	76·06
„ Purbeck	2·680 W.	167·50	Water, sea	1·027 Th.	64·18
„ „	2·599 Re.	162·43	„ rain	1·000	62·50
„ Roach Abbey (magnesium limestone) ..	1·893 R.	118·31	Whinstone (Scotch).. ..	2·760 W.	172·50
			Wood ashes	·933 P.	58·32
Stone, Tottenhoe (calcareous sandstone) ..	1·800 T.	112·50	„ petrified	2·341 P	146·31
			Zinc	7·200 Hu.	450·00
Stone, Woodstock flagstone	2·614 K.	163·37			

Part of the letters of reference are explained in a note to the preceding Table, the rest are as follows: Be. Belidor; Br. Brisson; Ha. Hatchet; Hu. from Hurst's 'Surveyor's Handbook'; K. from Kirwan's 'Mineralogy'; Re. Rennie, 'Philosophical Magazine,' vol. liii.; Ro. Rondelet; and Th. from Dr. Thomson's 'System of Chemistry,' 5th edition.

In bodies of a porous nature, the specific gravity, as given by the greater part of the Tables consulted by the Author, is much above the real weight of a given bulk of the material, as compared with water. The cause of this difference is the absorption which takes place when the body to be tried is immersed in water. Let A be the weight of a body in air, W its weight in water, a the weight of water it absorbs, and S the specific gravity; then $\frac{A}{A + a - W} = S$. When the absorption is nothing, or $a = o$; then $\frac{A}{A - W} = S$, which is the same as the common rule.

By the equation $\frac{A}{A + a - W} = S$, the specific gravities in the Table marked R and T have been determined. But this method does not apply to sand and other loose materials; therefore, to find the specific gravity of sand, a vessel which when filled contained a known weight of water, was filled with the sand to be tried, and weighed. The vessel used by the Author contained 1300 grains of water; therefore, as 1300 : weight of the sand : : 1 : specific gravity of the sand.

By the method of mixing equal volumes of water and sand, a solid specimen of quartz would be of the same specific gravity as its sand would be: but it is well known that a stone crushed into sand occupies more space than the solid stone did; and therefore the method is erroneous.

The specific weight of a cohesive earth, such as clay or loam, is best obtained by cutting a cubical piece, and carefully measuring and weighing it. This method is given by Kirwan in his 'Essay on the Analysis of Soils,' and is accurate enough for most practical purposes.

INDEX.

C.

Q.

R.

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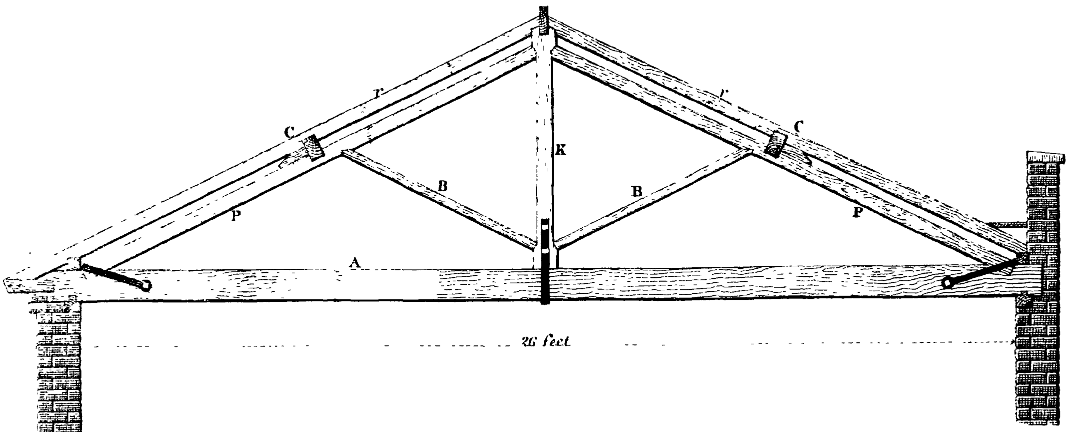

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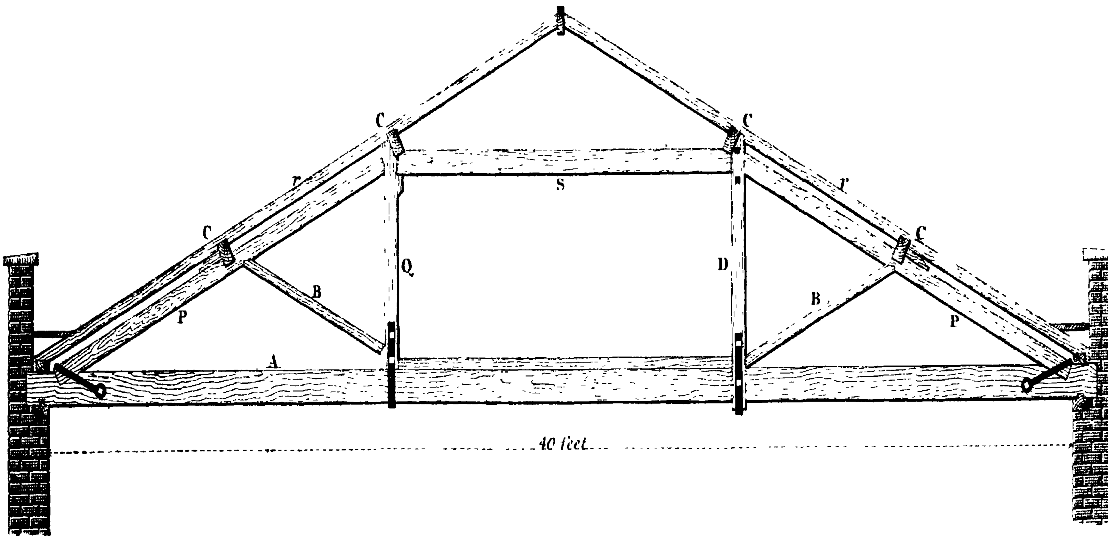

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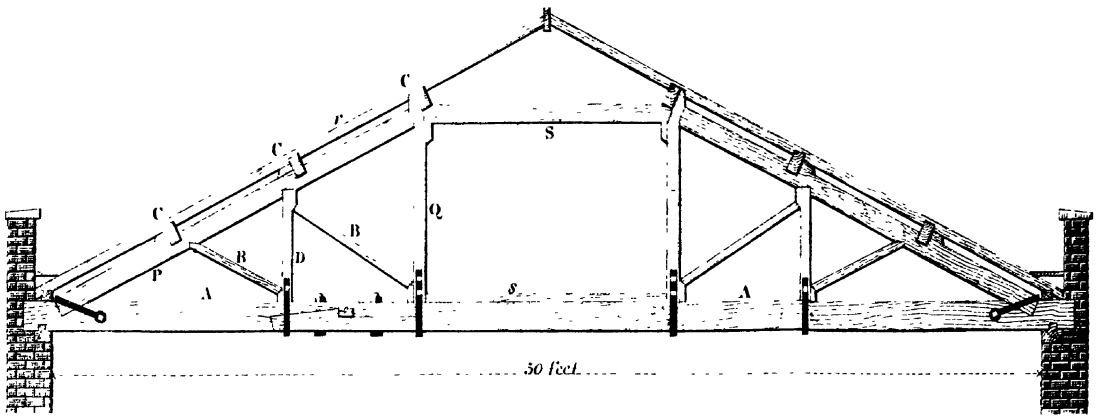

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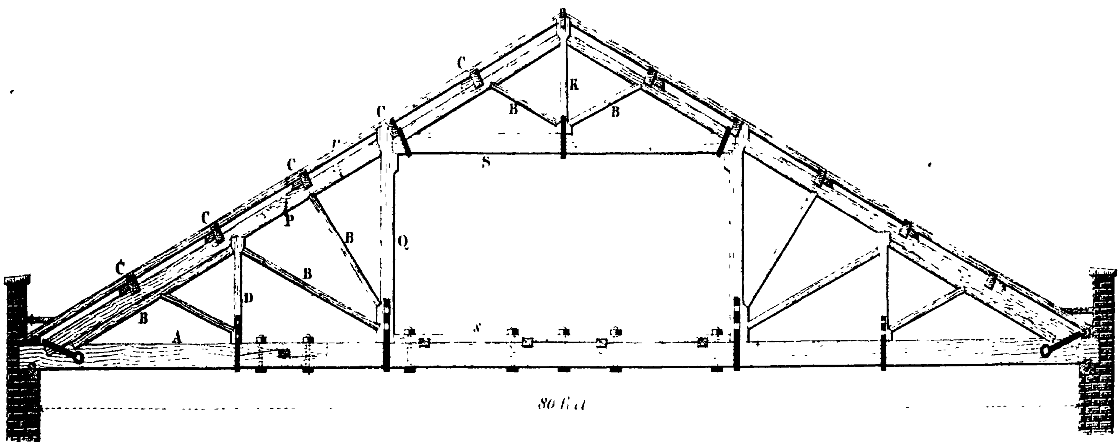

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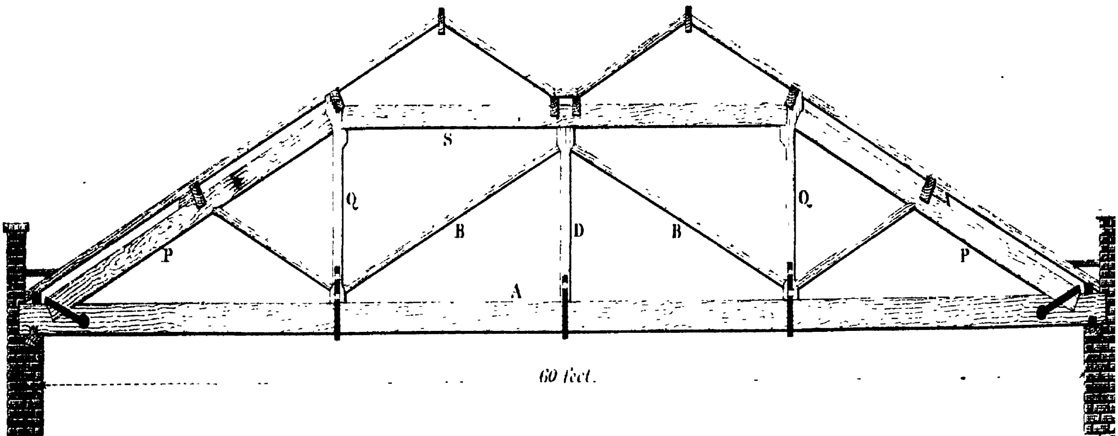

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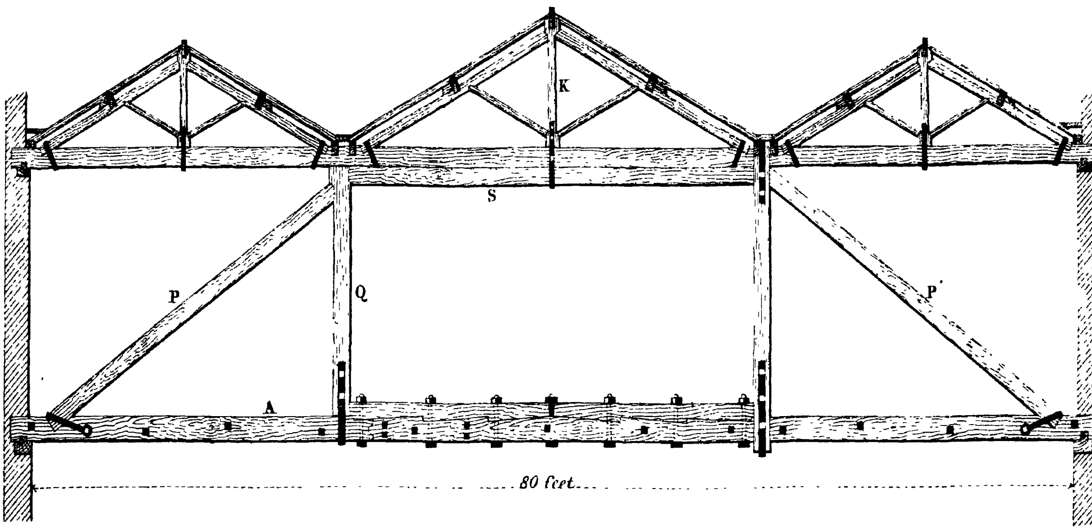

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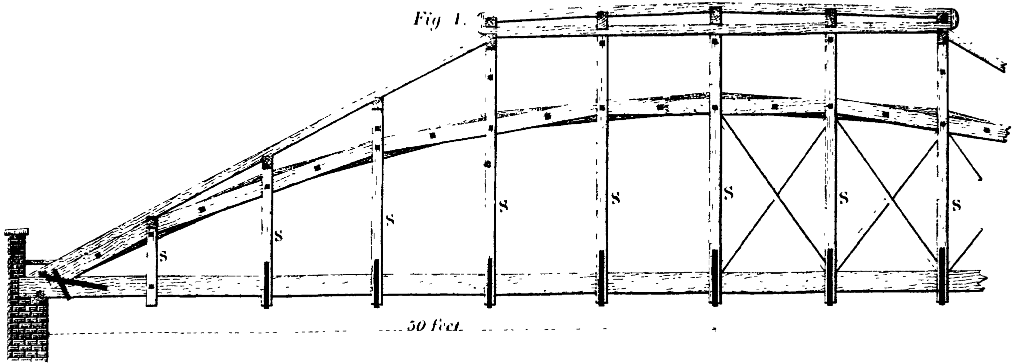

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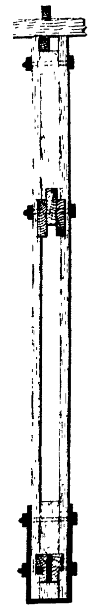

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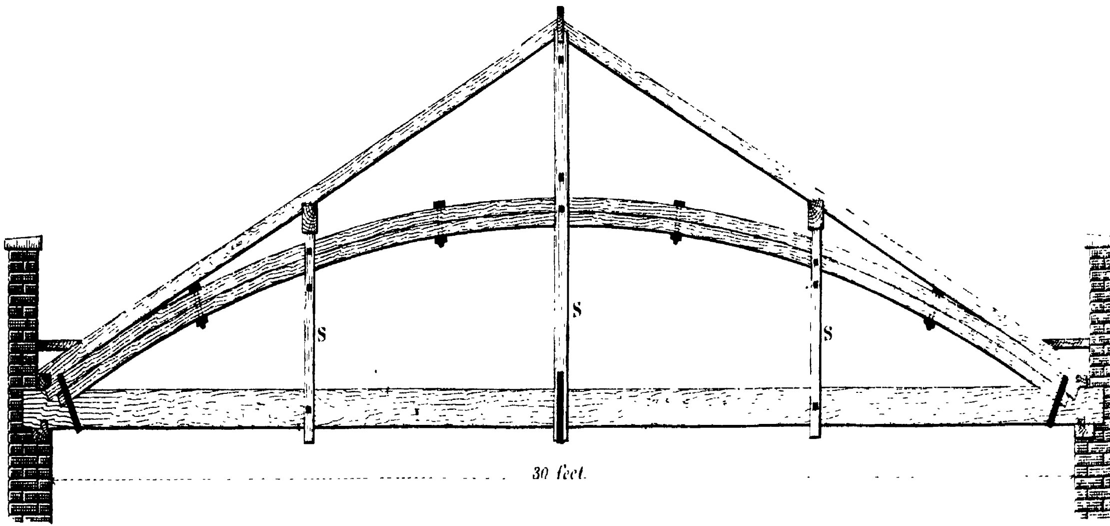

Plate IX.

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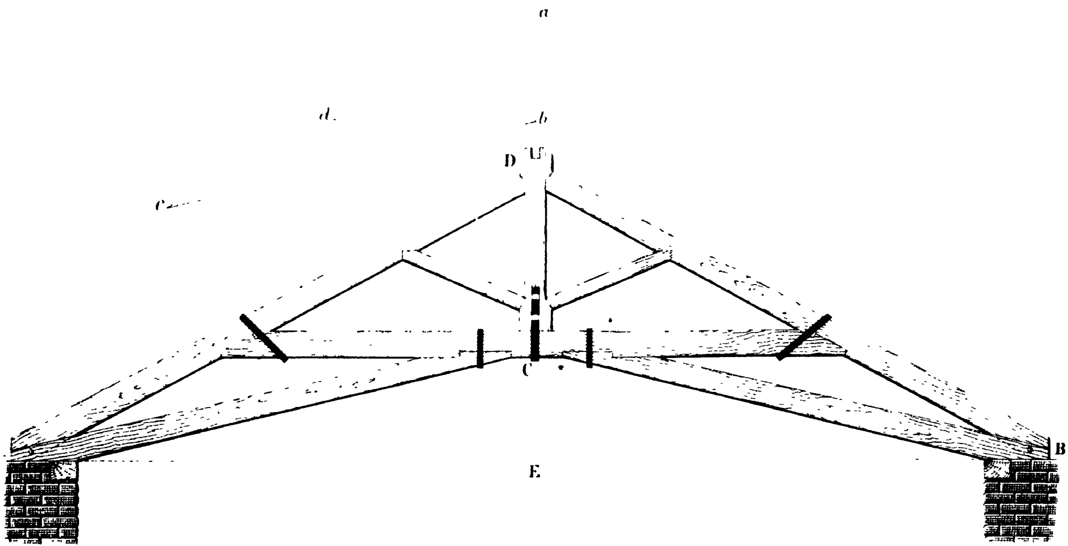

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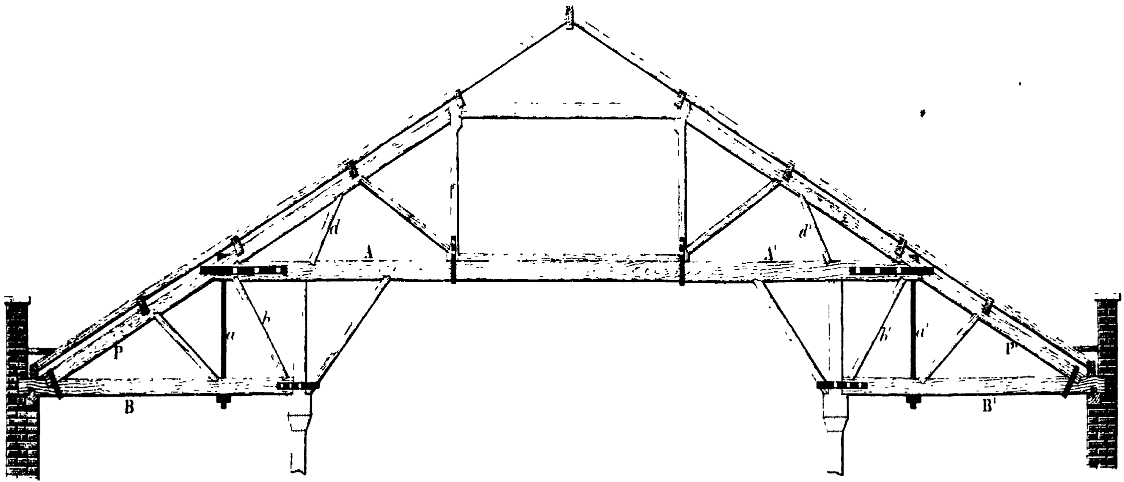

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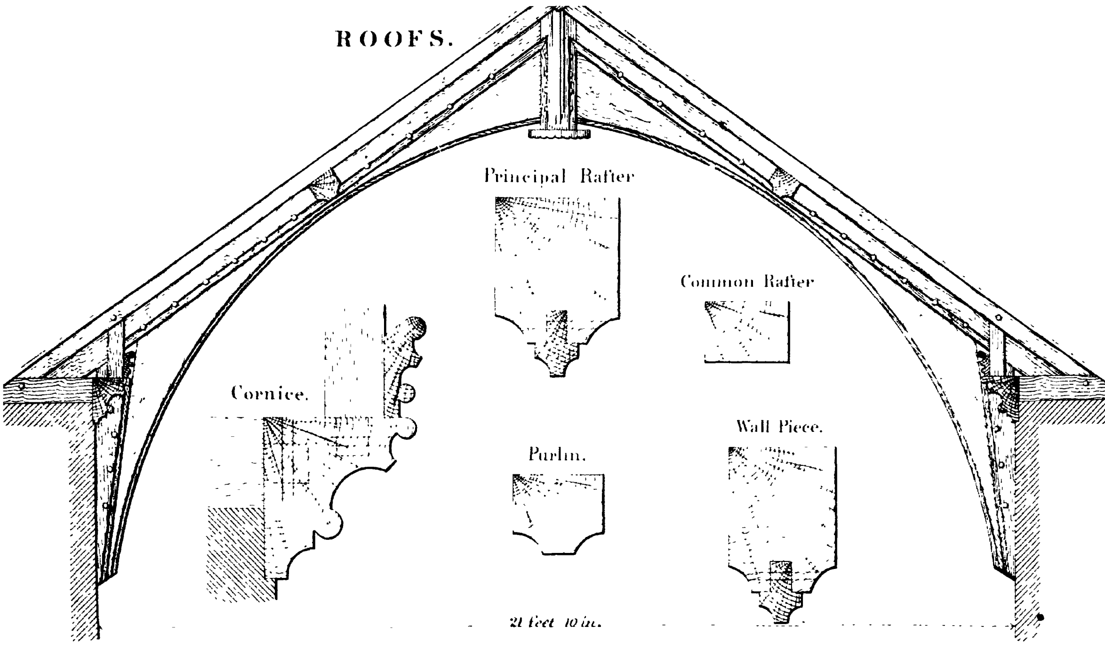
Principal Rafter
Common Rafter
Cornice.
Purlin.
Wall Piece.
21 feet 10 in.

Plate XII.

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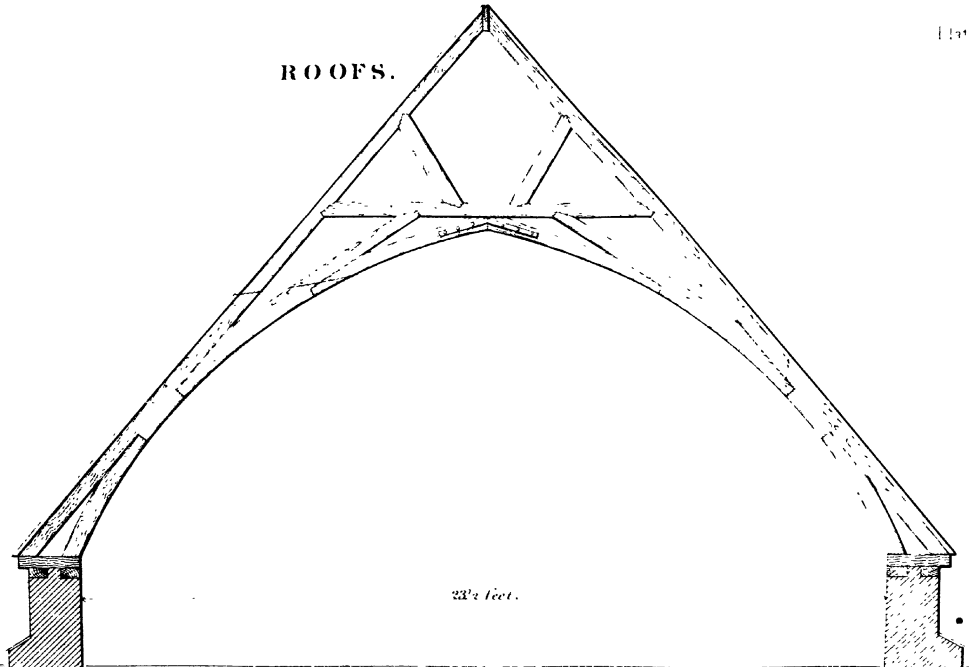

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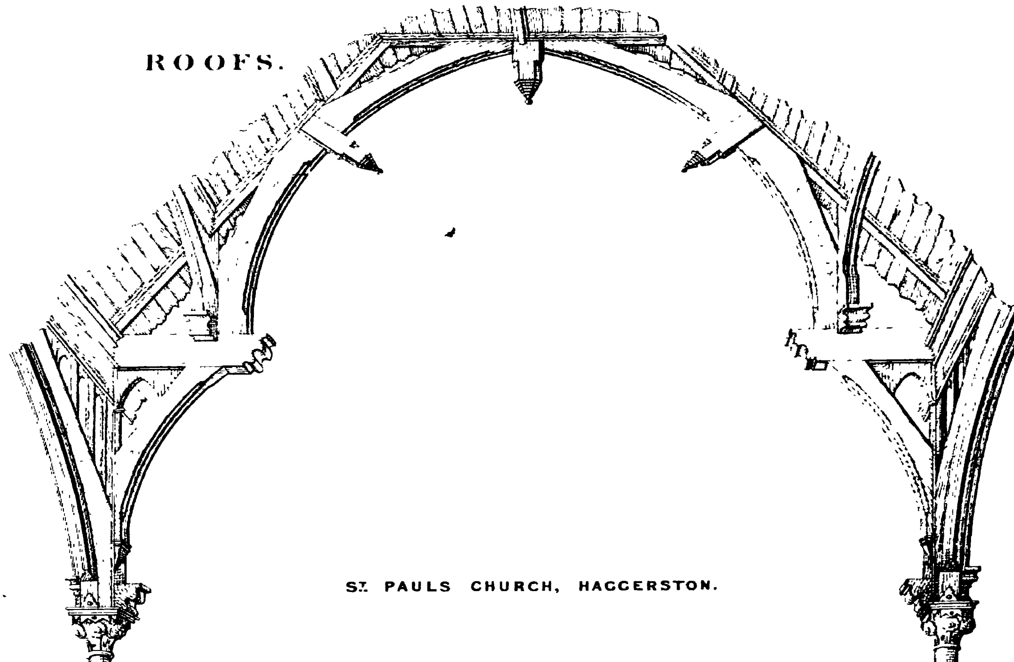

ST. PAULS CHURCH, HAGGERSTON.

Plate XIV.

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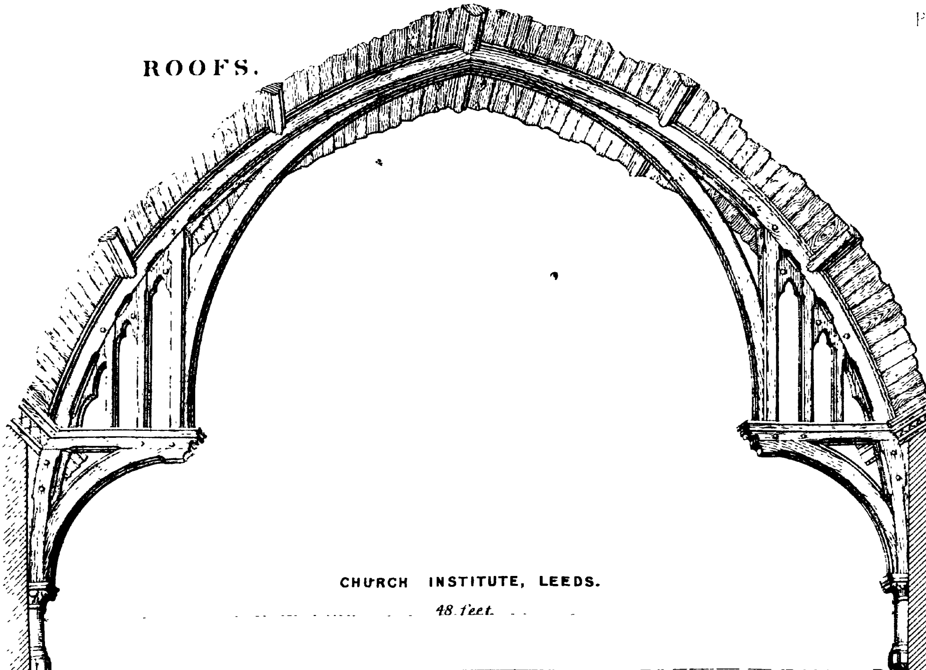

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48 feet.

Plate XV.

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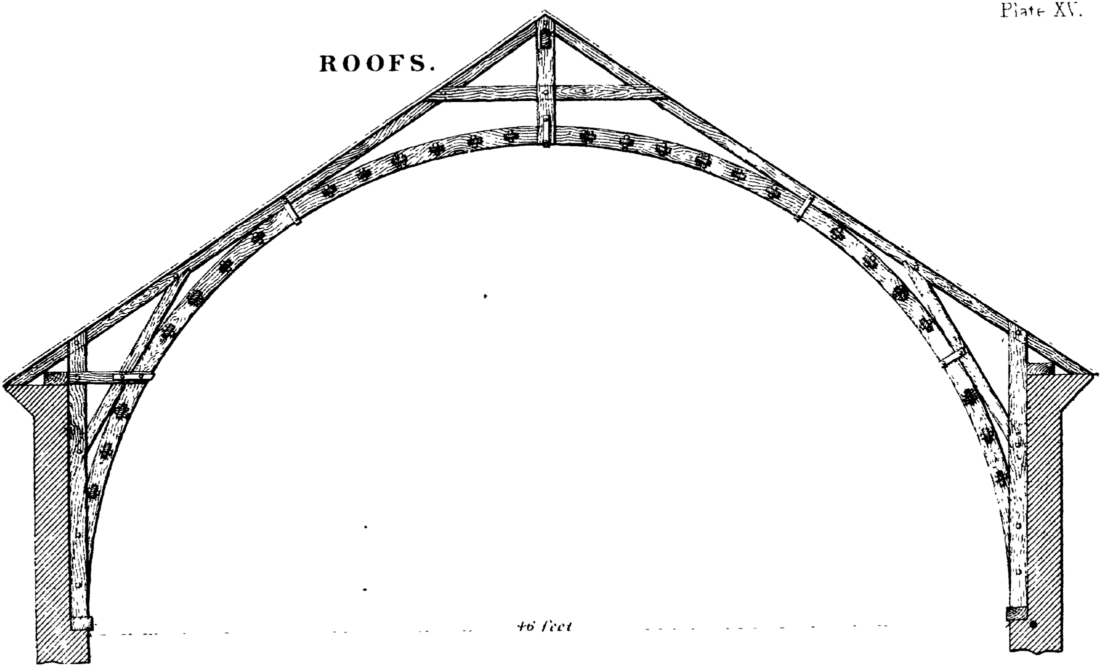

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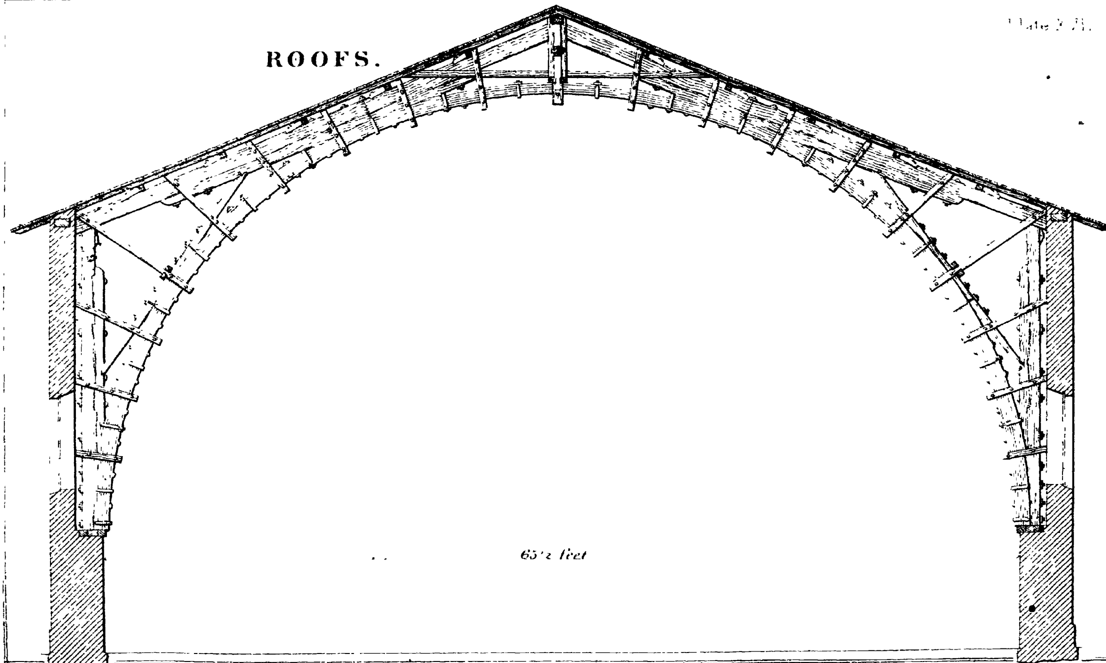

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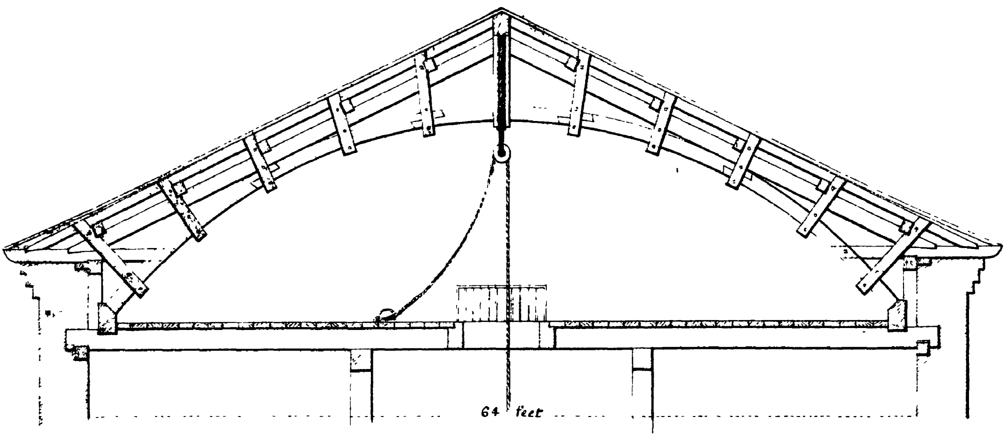

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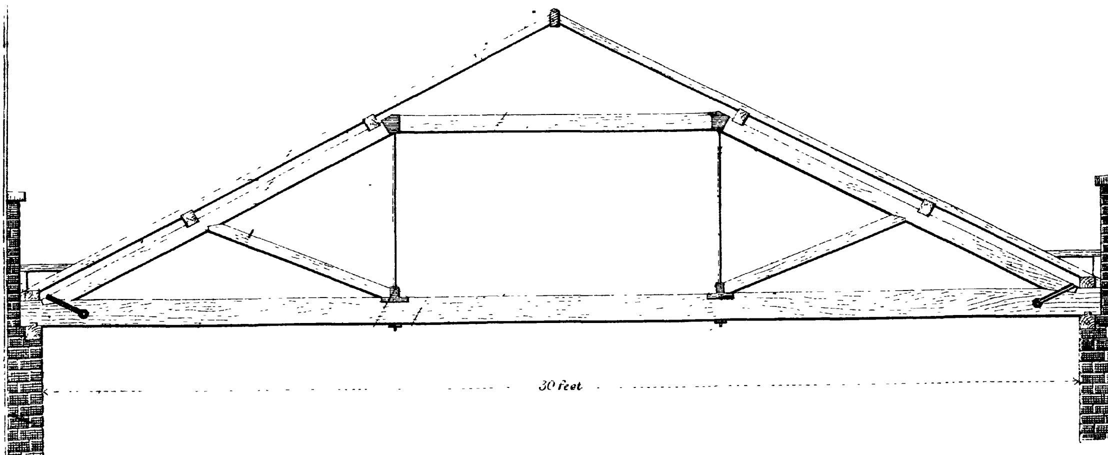

Thos. Kell Lithographer

Plate XIX

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Fig. 1.

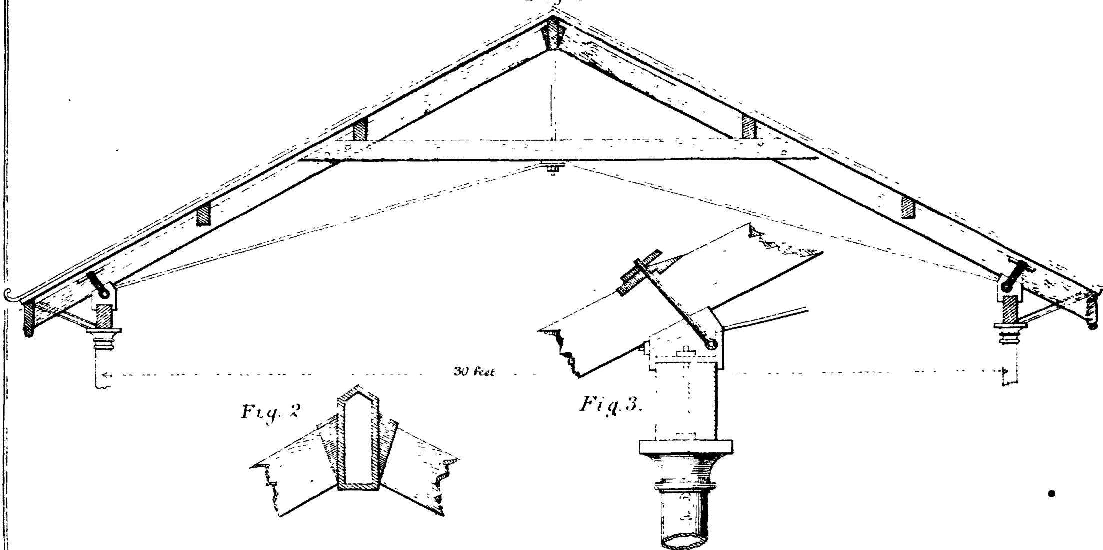

Fig. 2

Fig. 3.

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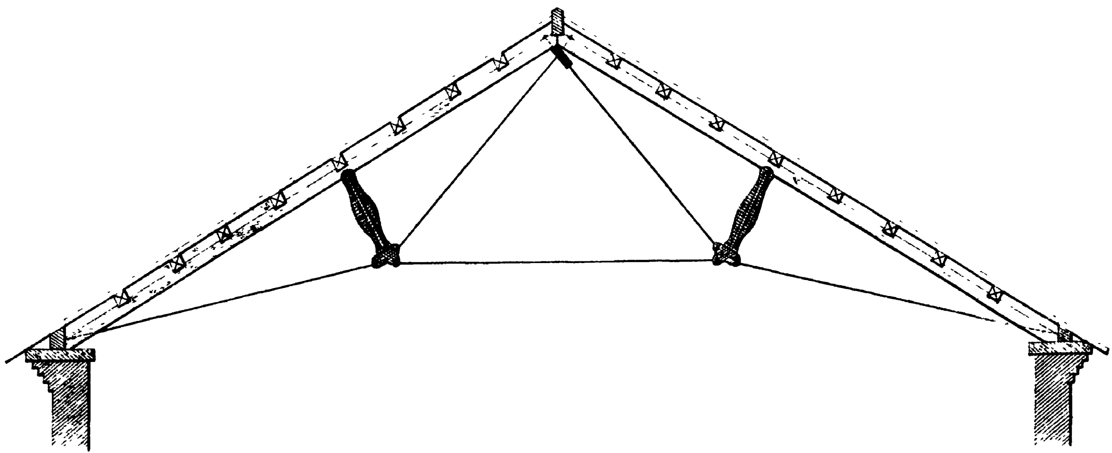

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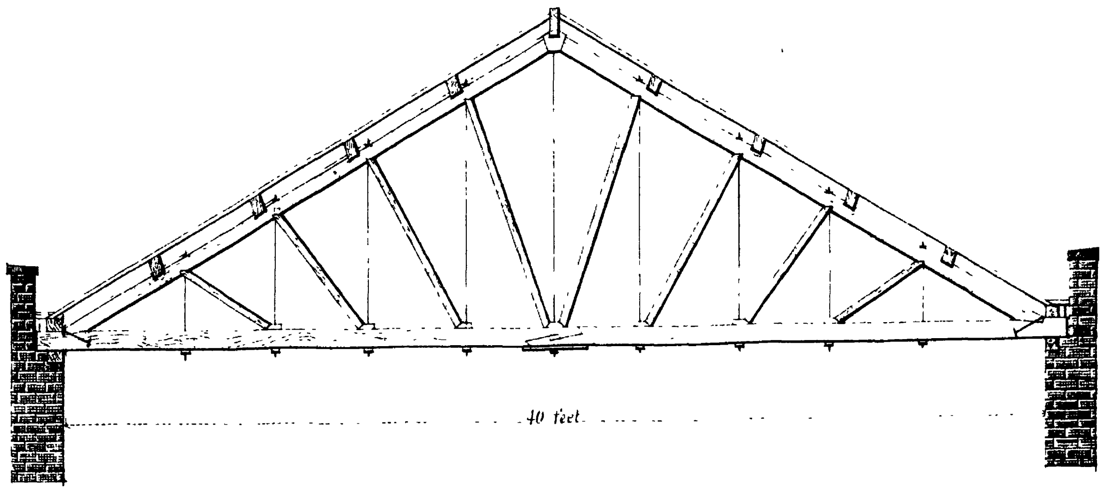
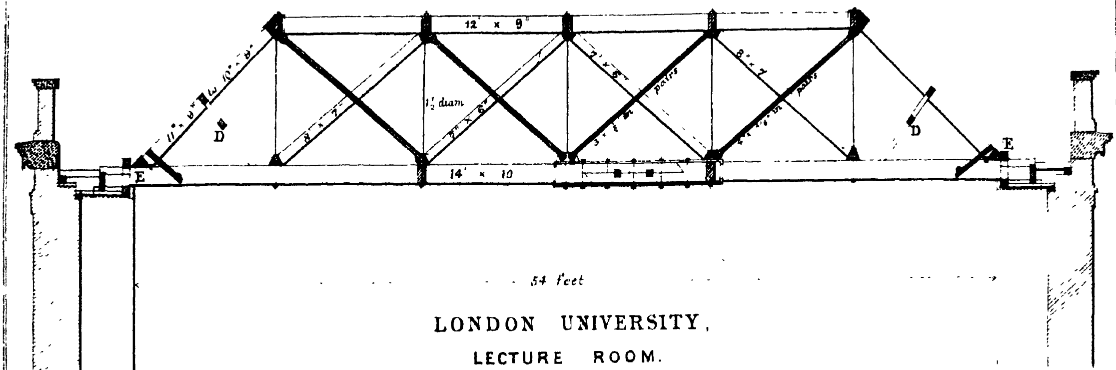


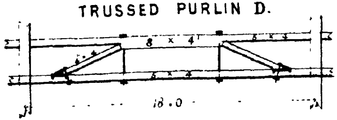
OO

PRINCIPAL TRUSS.

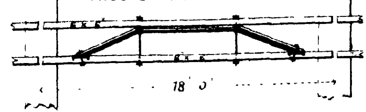


LONDON UNIVERSITY,
LECTURE ROOM.

TRUSSED PURLIN D.



TRUSSED POLE PLATE E



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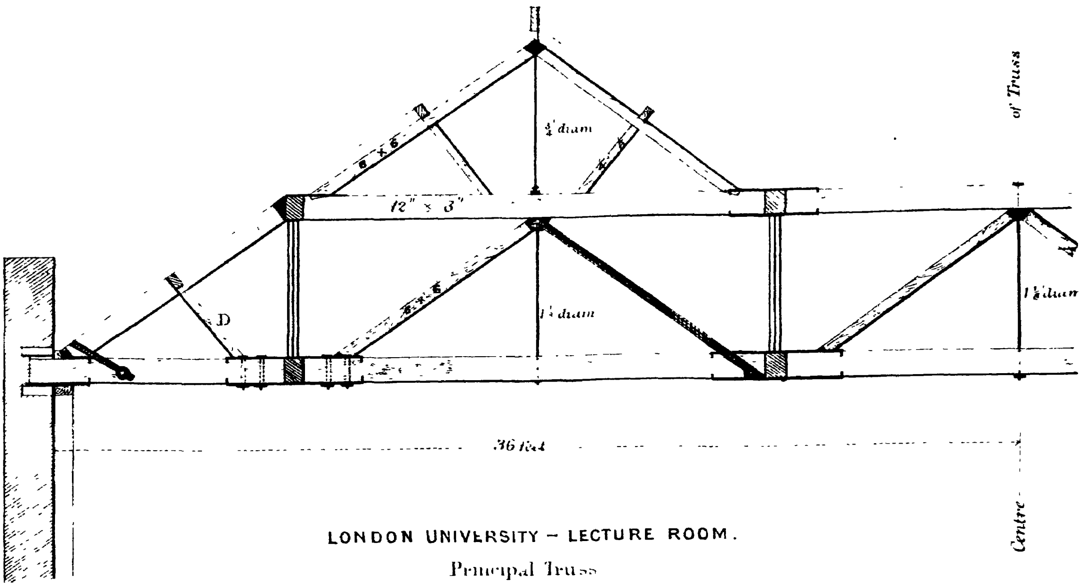
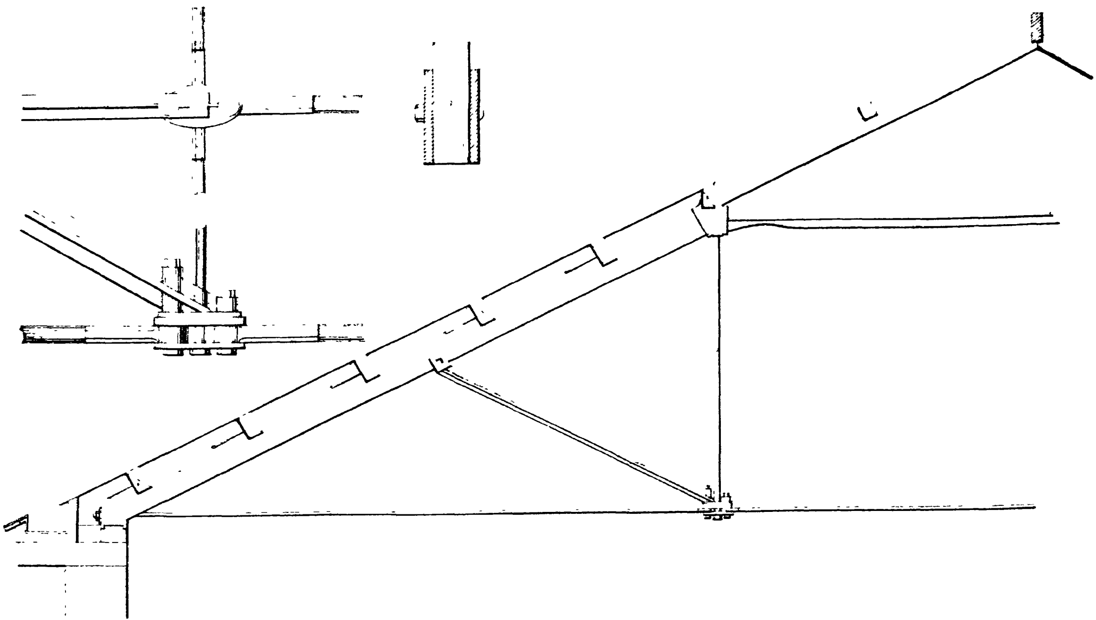


LONDON UNIVERSITY – LECTURE ROOM.

Principal Truss

ROOFS.



ROOFS.

Plate XXV.

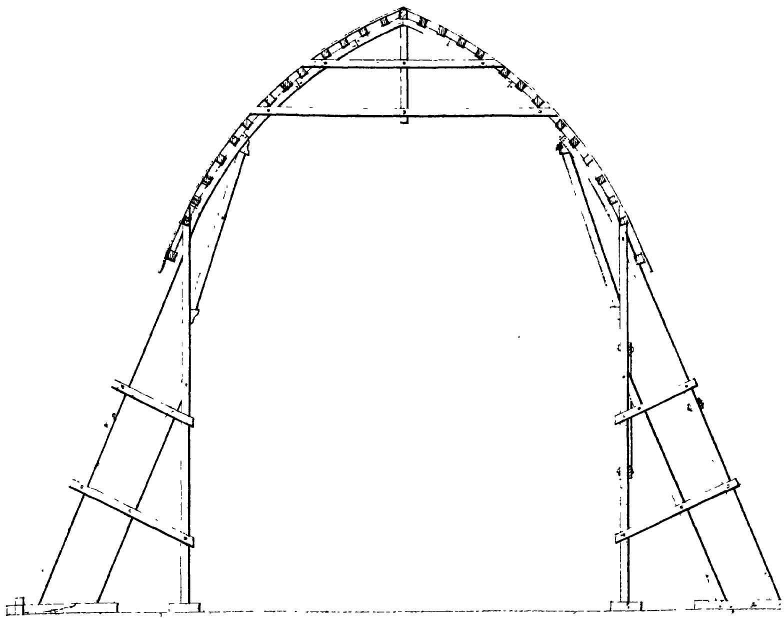
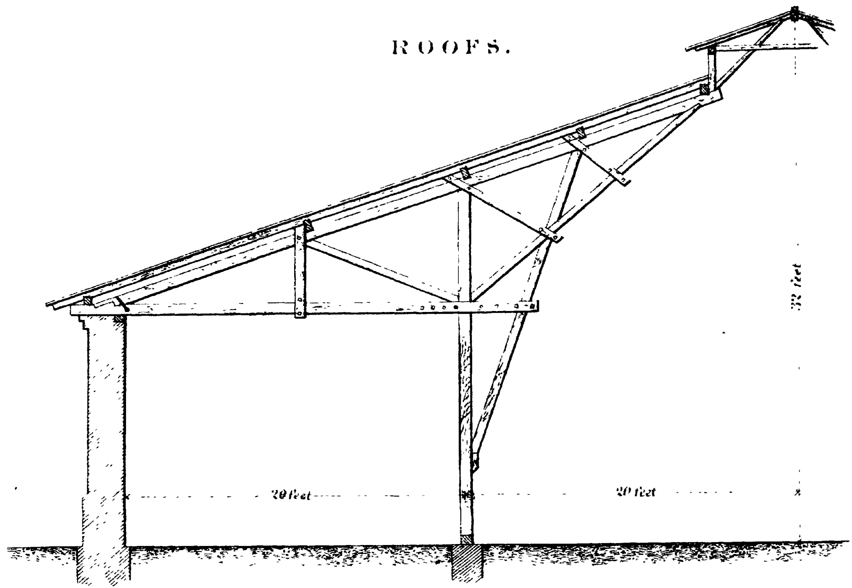
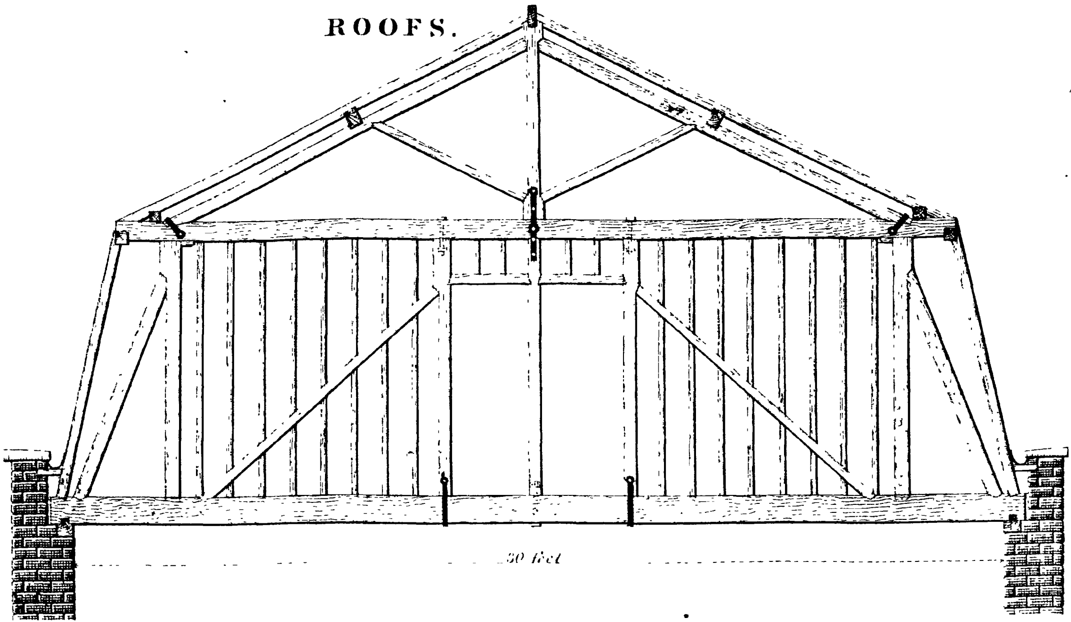


Plate XXVI

ROOFS.



ROOFS.



ROOFS.

Fig 1

ROOF OF THE BASILICA OF S.T PAUL AT ROME

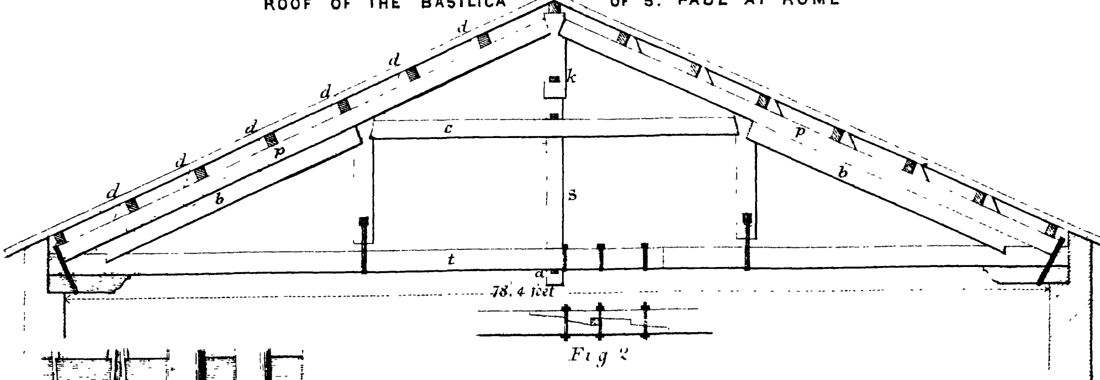


Fig 2

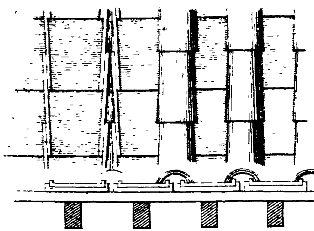


Fig 3.

DOMES.

Fig. 1.

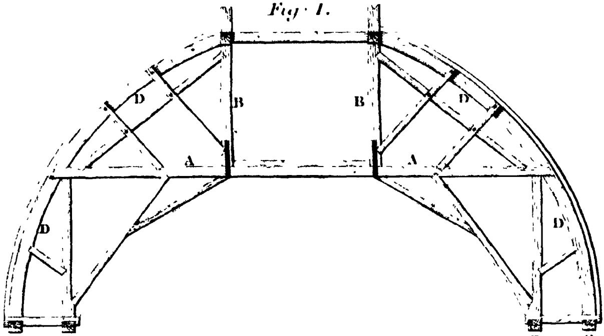


Fig. 2

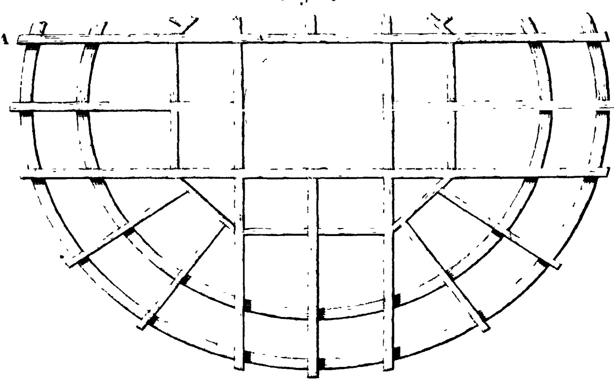


Fig. 3

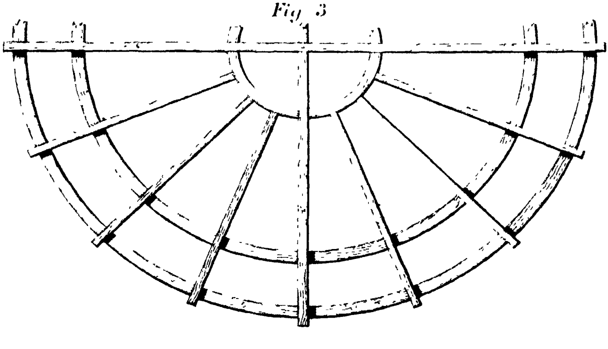


Plate XXX

DOMES.

Fig: 1.

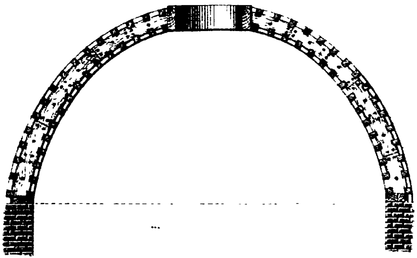


Fig. 3.

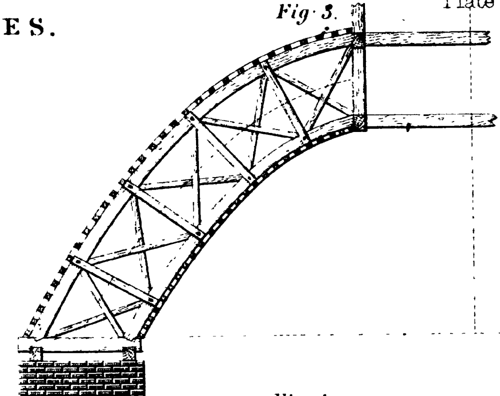


Fig. 2

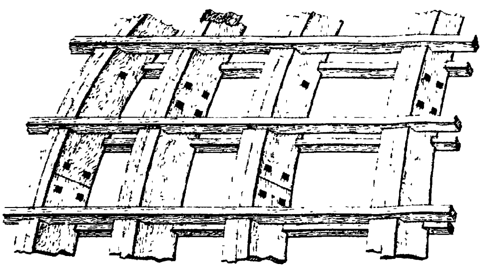


Fig. 4.

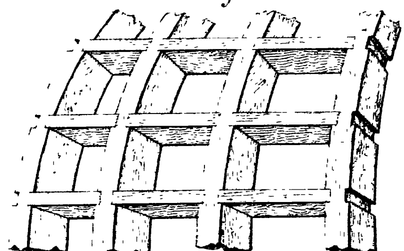


Plate XXXI.

DOMES.

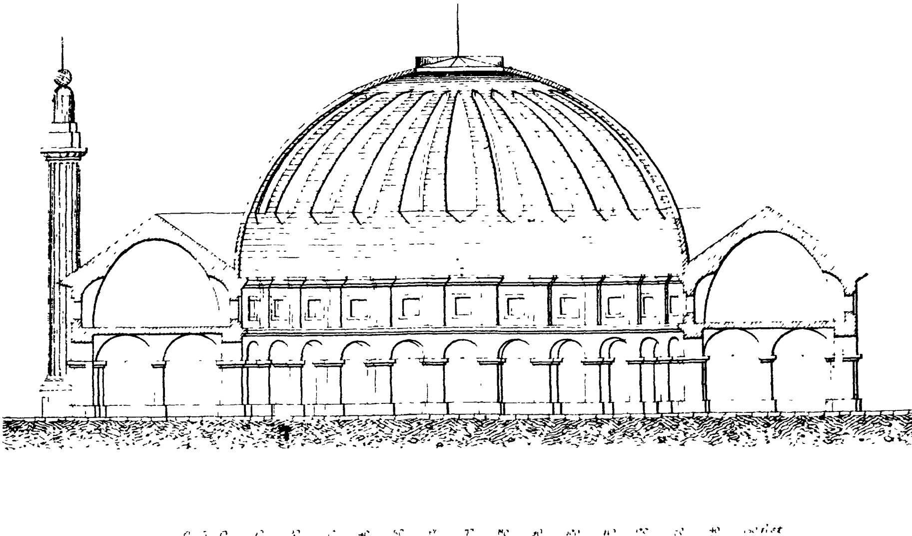


Plate XXXII

PARTITIONS.

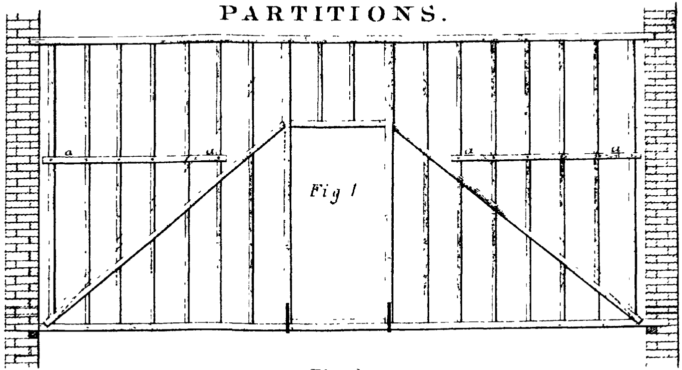
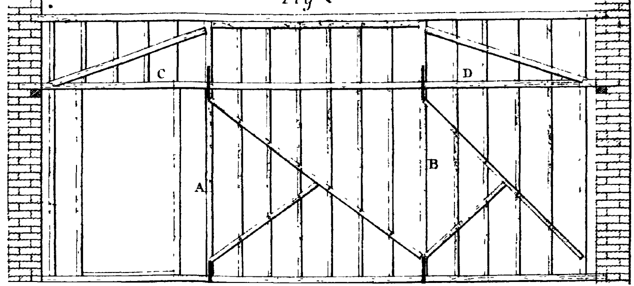


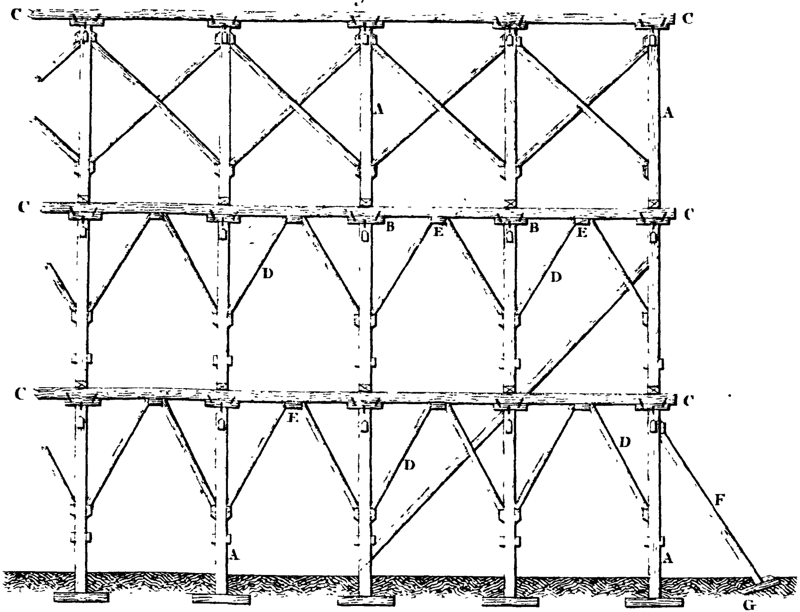
Fig 1

Fig 2



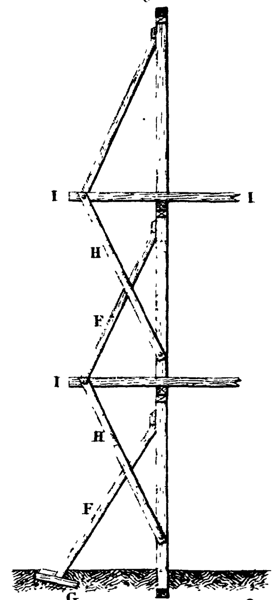
SCAFFOLDS AND GANTRIES.

Fig 2.



Elevation

Fig: 1.

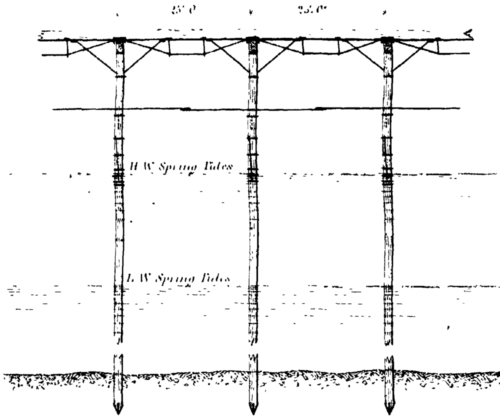


Section

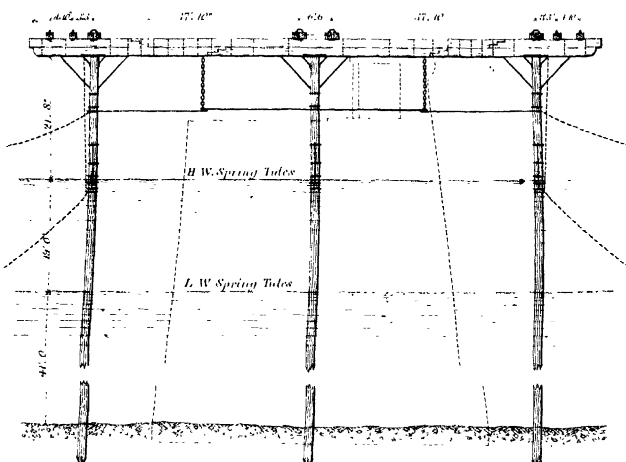
Plate XXXIV

STAGING.

DOVER PIER.



Longitudinal Section.



Transverse Section.

CENTRES.

Fig. 1.

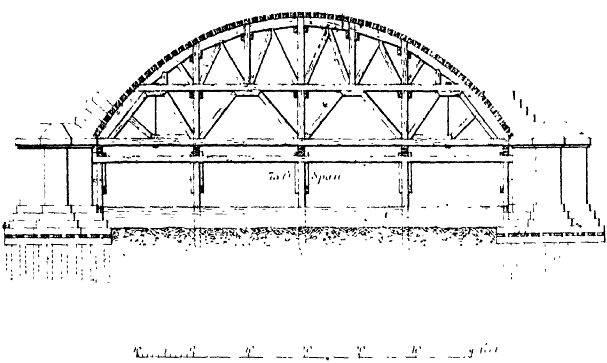


Fig. 2

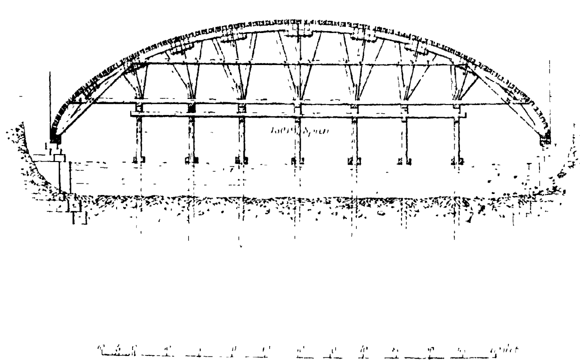


Plate XXXVI

CENTRES.

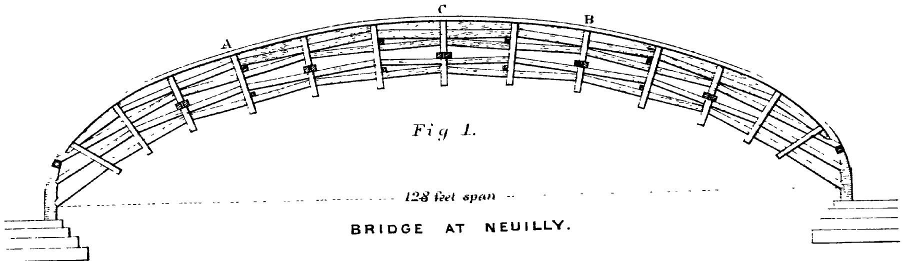


Fig 1.

BRIDGE AT NEUILLY.

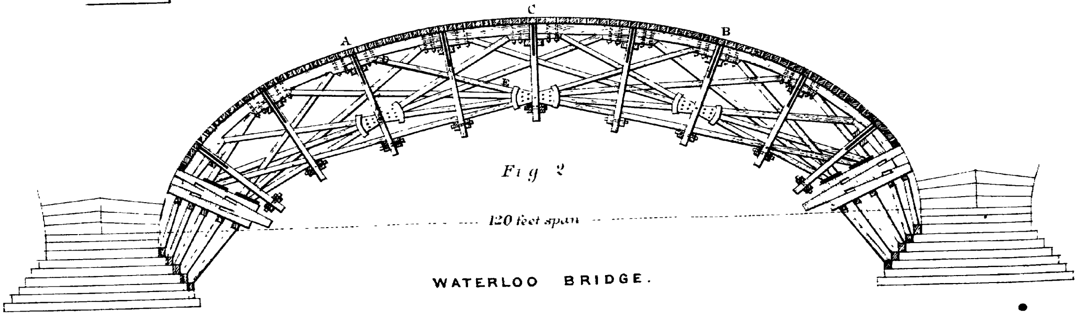


Fig 2

WATERLOO BRIDGE.

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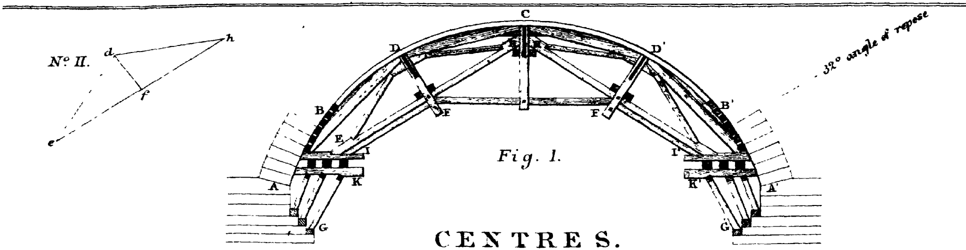
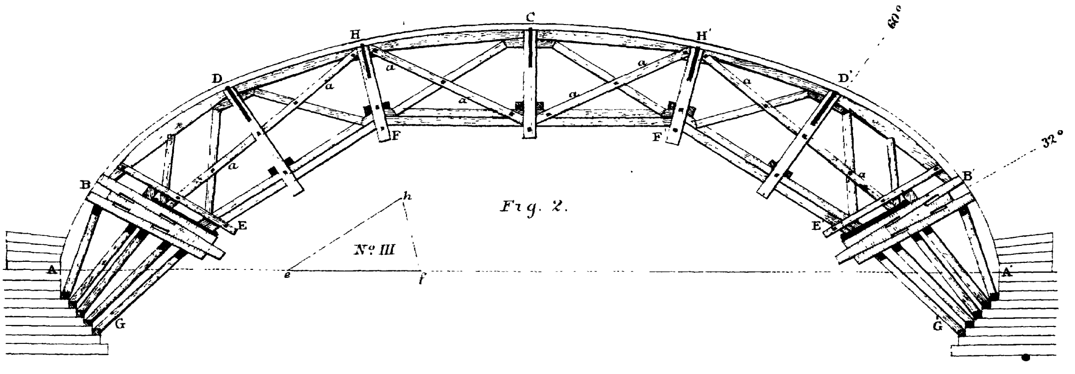
Thos Kell, Lithographer, 40 King St Covent Garden

Plate XXXVII



CENTRES.



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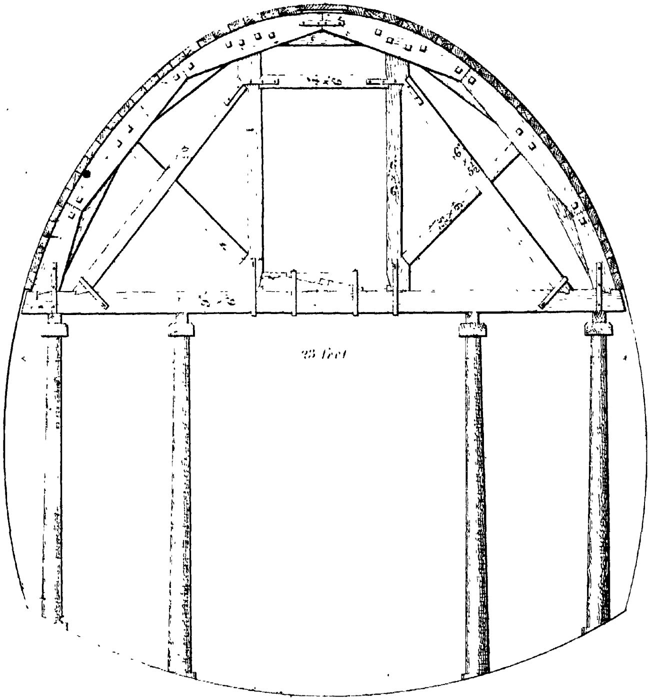
Thos Kell Lithographer
40 King St Covent Garden

Plate XXXVIII.

CENTRES.



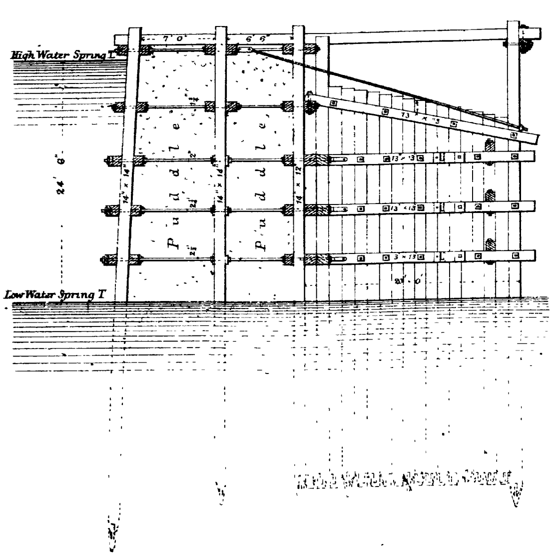
London E & F N Spon, 48, Charing Cross

Thos Kell, Lithographer
40, King St Covent Garden

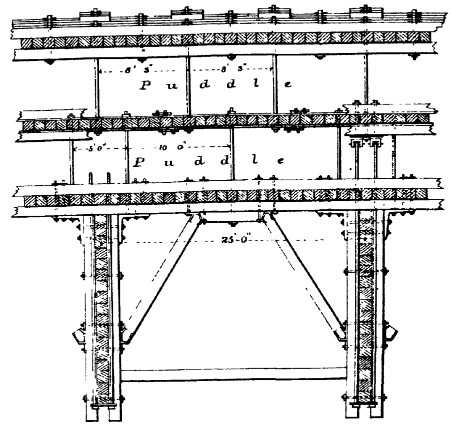
Plate XXXIX.

COFFERDAMS.

TRANSVERSE SECTION.



PLAN.



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Thos Kell, Lithographer, 40, King St Covent Garden

BRIDGE AT BAMBERG.

Fig 1.

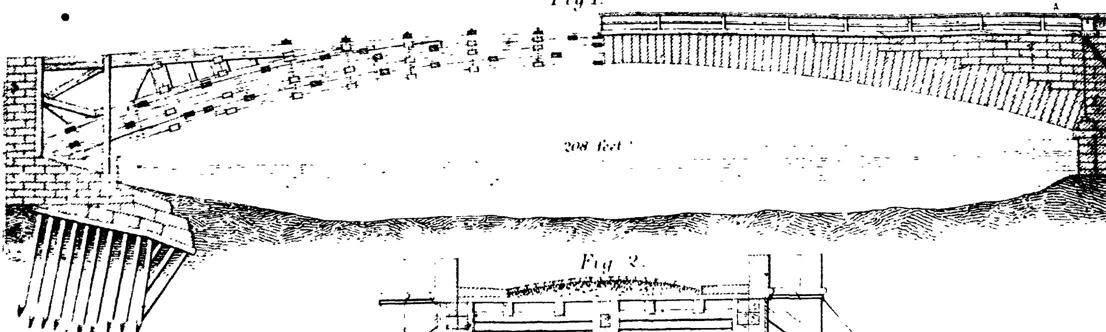
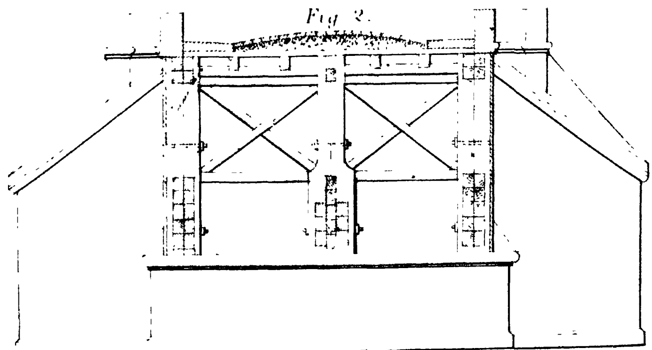
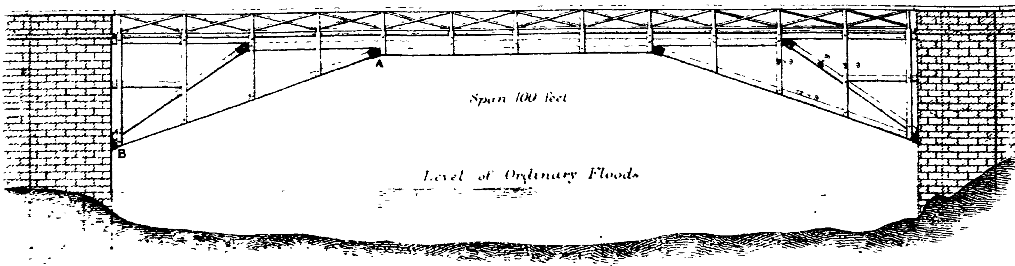


Fig 2.

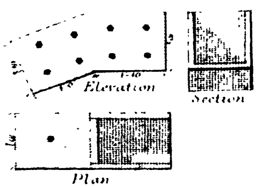


BRIDGES.

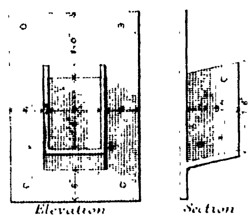
Plate XLI



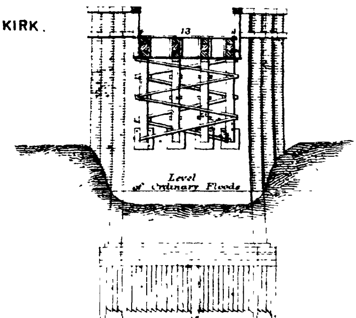
TIMBER BRIDGE OVER THE RIVER SPEY AT LAGGAN KIRK.



SOCKET AT A.



SOCKET AT B



TRANSVERSE SECTION AT MIDDLE OF BRIDGE.

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Thos Kell Lithographer 40 King St Covent Garden.

Plate XLII

BRIDGES.

Fig. 1

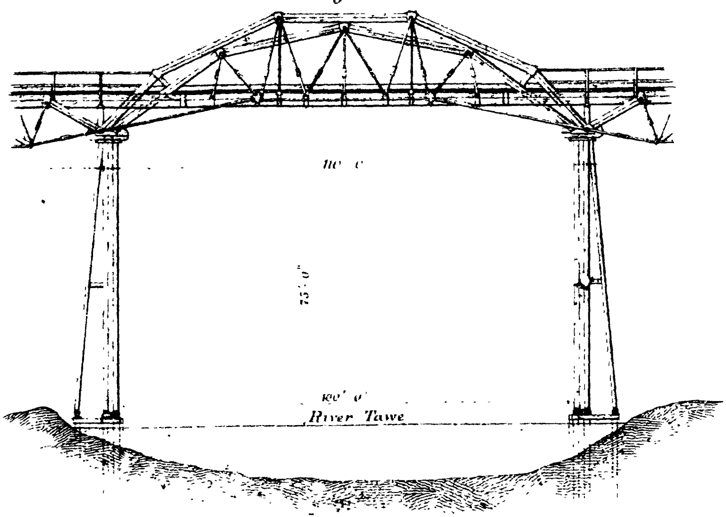
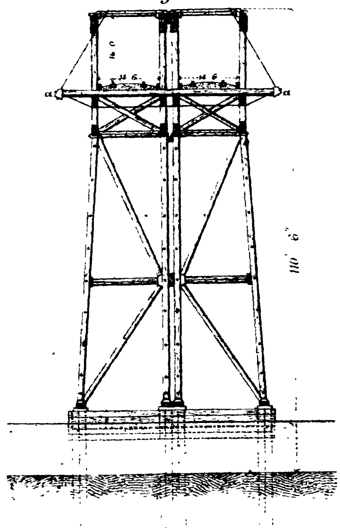


Fig. 2.

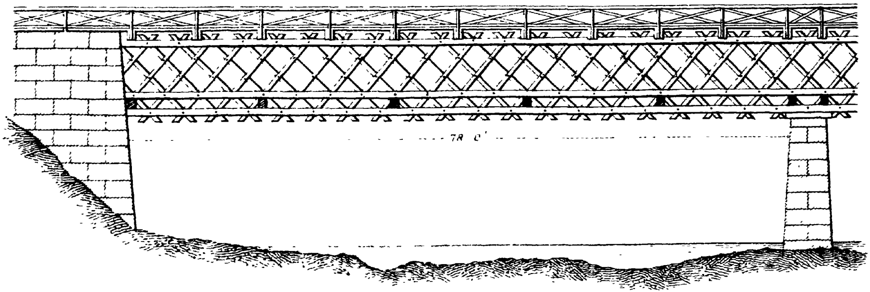


LANDORE VIADUCT.

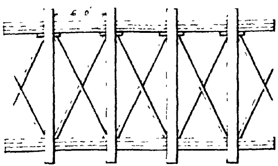
BRIDGES,

LATTICE BRIDGE.

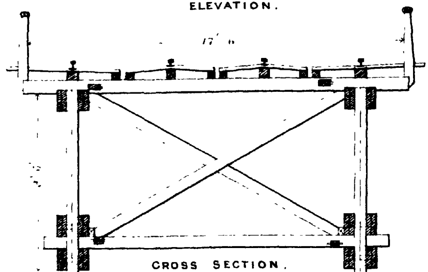
Plate XLIII



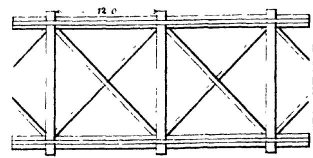
ELEVATION.



PLAN UNDER ROADWAY



CROSS SECTION.



PLAN AT BOTTOM OF GIRDERS.

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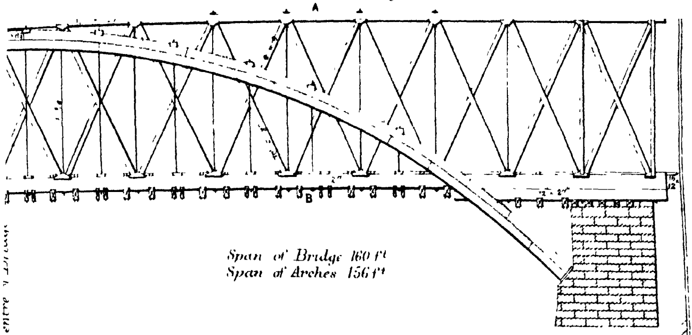
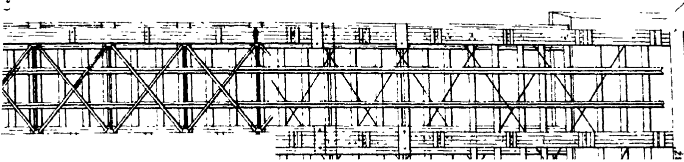
Thos Kell Lithographer
40 King St Covent Garden

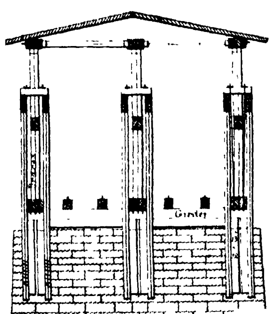
IMPROVED HOWE TRUSS

hiladelphia and Reading Railw



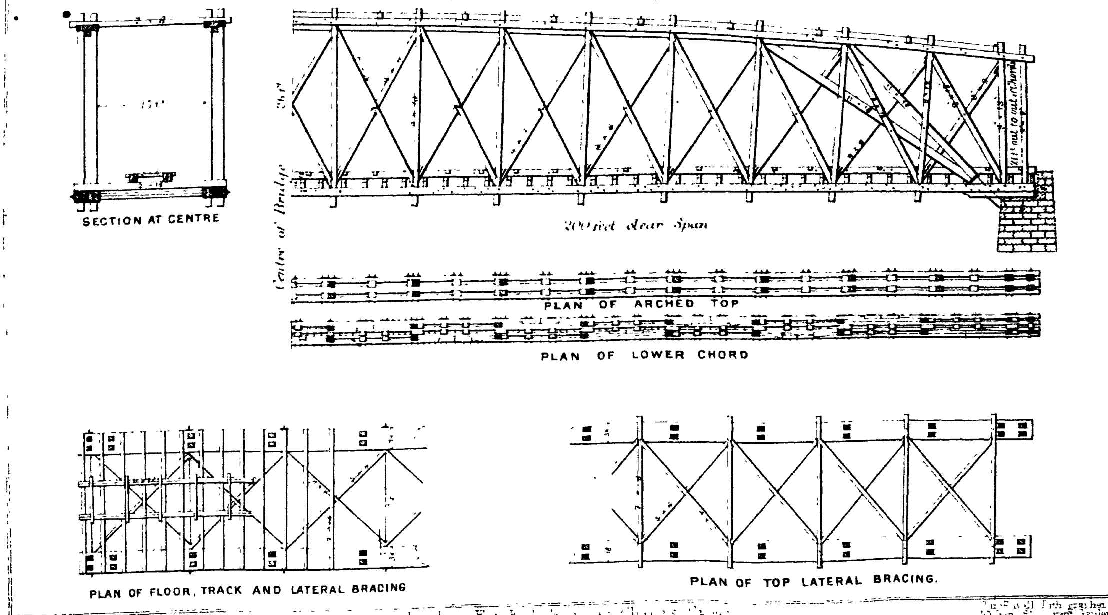


PLAN SHEWING ARCH, TOP AND BOTTOM CHORDS



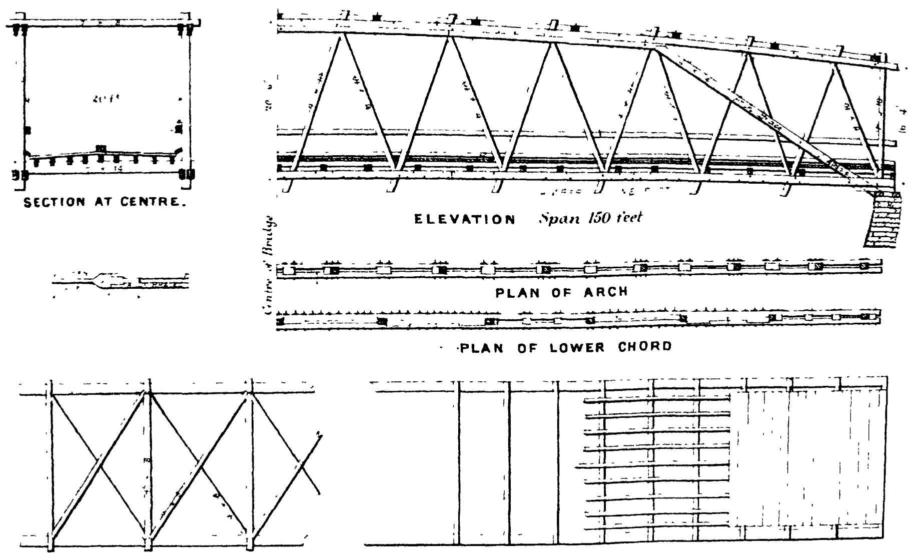
CROSS SECTION A.B

BRIDGES.
McCallum's Principle.



BRIDGES,

Mc Callum's Principle.



SECTION AT CENTRE.

ELEVATION *Span 150 feet*

PLAN OF ARCH

PLAN OF LOWER CHORD

PLAN OF TOP BRACING

PLAN OF FLOORING

BRIDGES.

Fig 1

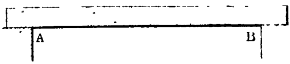


Fig 2

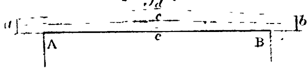


Fig 3

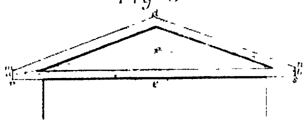


Fig 4.

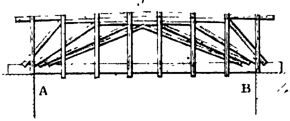


Fig 5

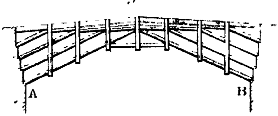


Fig 6

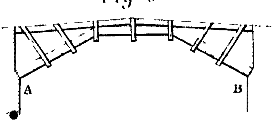
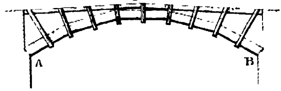


Fig. 7



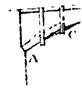


Fig. 9.

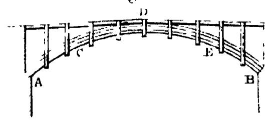


Fig 10

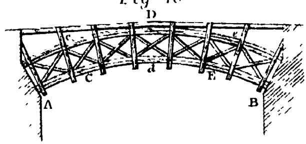


Fig 11

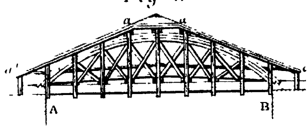


Fig 12.

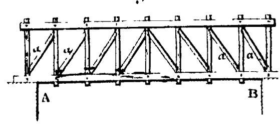


Plate XLVIII.

BRIDGES.

Fig 1.

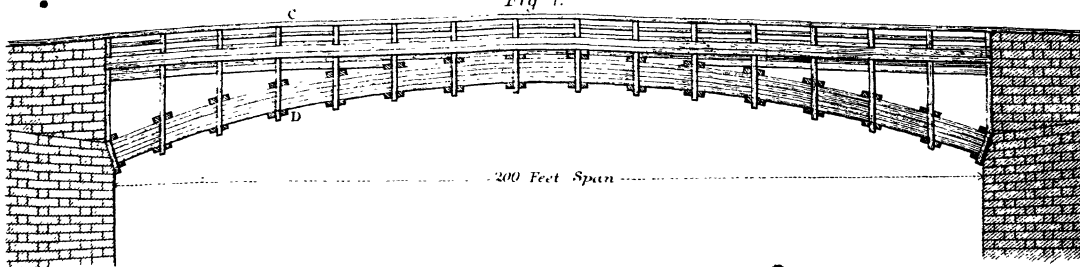
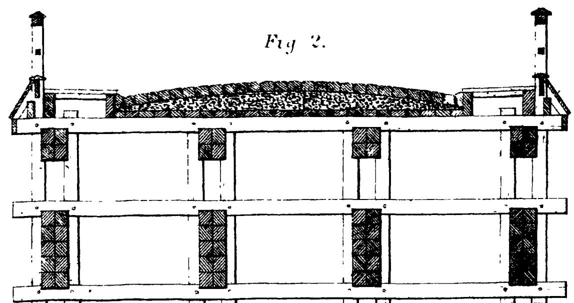


Fig 2.



Section at C D.

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Thos Kell, Lithographer,
40, King St Covent Garden

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